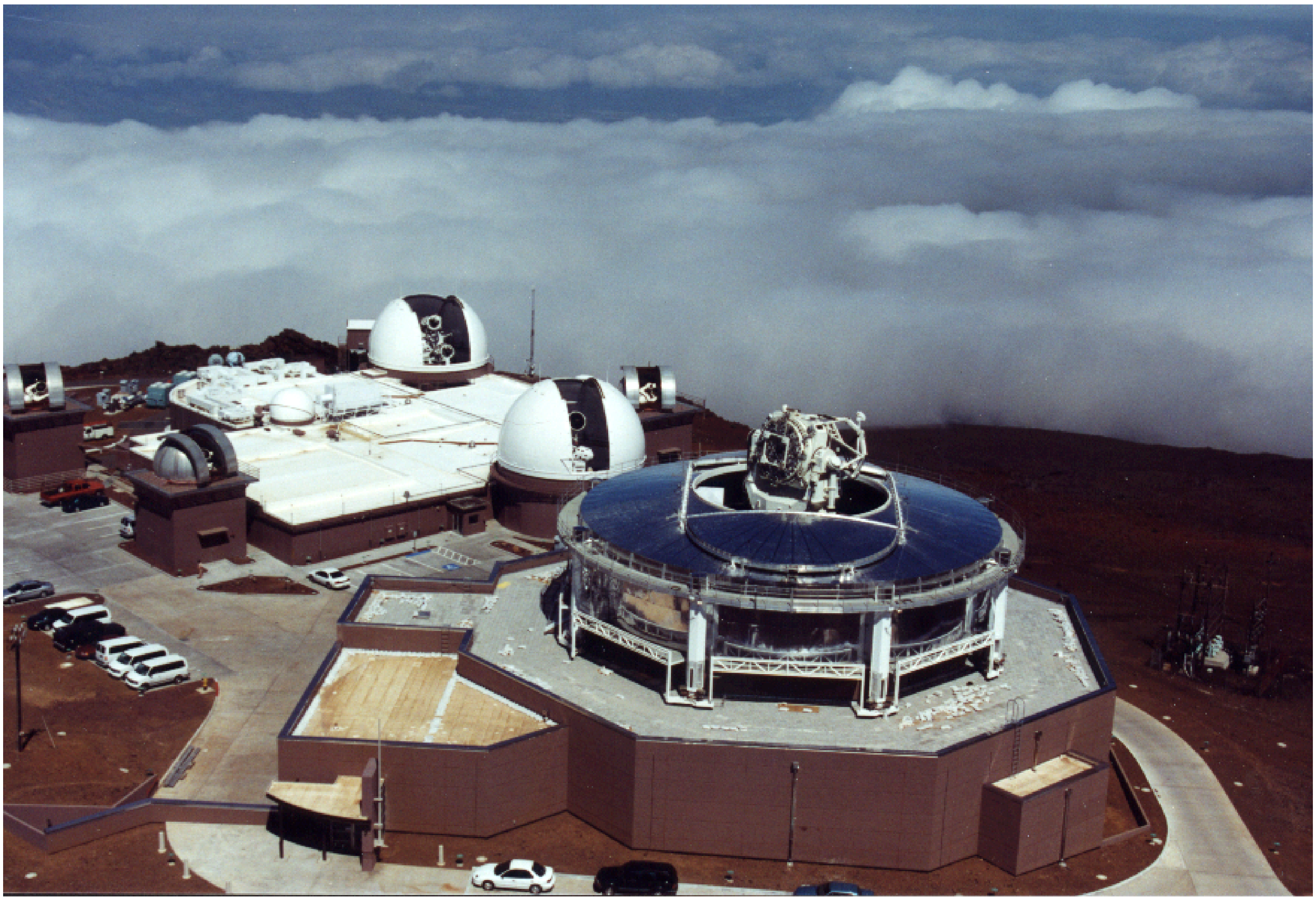
AMOS

USER'S MANUAL



MAUI SPACE SURVEILLANCE SYSTEM

AMOS USER'S MANUAL

Revision 12

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Prepared for
Det 15, Air Force Research Laboratory
Kihei, Maui, Hawaii

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Front Cover

Aerial view looking west. Maui Space Surveillance System atop *Haleakala* at 10,023 feet.

Cover Photography

Frank Rizzo - Rocketdyne Technical Services

http://www.maui.afmc.af.mil

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Abstract

The Maui Space Surveillance System (MSSS) is located on the summit of 10,000-foot *Haleakala* on the island of Maui, Hawaii. The MSSS is a space surveillance and Research and Development (R&D) site. The Air Force Maui Optical and Supercomputing (AMOS) detachment of the Air Force Research Laboratory (AFRL) operates the MSSS, a national resource providing measurement support to various government agencies and the scientific community. The Maui Space Surveillance Complex (MSSC) is composed of two facilities: The MSSS and the Ground-based Electro-Optical Deep Space Surveillance (GEODSS) system.

The MSSS is a state-of-the-art electro-optical facility. It combines large-aperture tracking optics with visible and infrared sensors to collect data on sub-orbital, near earth and deep space objects. Optical equipment at MSSS includes a 3.6-meter telescope, a 1.6-meter telescope, two 1.2-meter telescopes on a common mount, a 0.8-meter beam director/tracker, and a 0.6-meter laser beam director, and a 0.4-meter Raven telescope. The telescopes support a wide variety of sensor systems, including compensated and uncompensated imaging systems, conventional and contrast mode photometers, infrared radiometers, low light level video systems and acquisition telescopes.

This manual presents a summary of AMOS systems, capabilities and support procedures. It includes a description of the kinds of mission objectives that can be satisfied, and the procedures to be used for requesting support. Pre-mission planning and data reporting procedures are also discussed. A section of the manual is dedicated to the visiting experimenter, whether planning a site visit or an extended stay for research. An acronym list is included in the appendices.

The technical and administrative support facility is located in the Maui Research and Technology Park in Kihei, Maui. The Premier Place building houses employee offices, a technical library and meeting rooms including a conference room connected to the MSSS with a two-way microwave teleconferencing link. The Maui High Performance Computing Center (MHPCC) is located in the same Park.

Section 1 - INTRODUCTION

AMOS

The MSSC includes MSSS and a contiguous GEODSS facility. GEODSS shares some of the AMOS resources but is otherwise an independent entity. The combined MSSS facilities have measurement capabilities that exploit its:

- Unique vantage point for observing sub-orbital vehicles, launched from Vandenberg Air Force Base, rockets launched from Barking Sands on the neighboring island of Kauai and endoatmospheric targets such as aircraft and missile simulator drones, as shown in Figure 1-1.
- Favorable low-latitude location (20.7°N) for satellite measurements.
- Excellent atmospheric characteristics for an observatory.
- Ease of access for visiting experimenters.

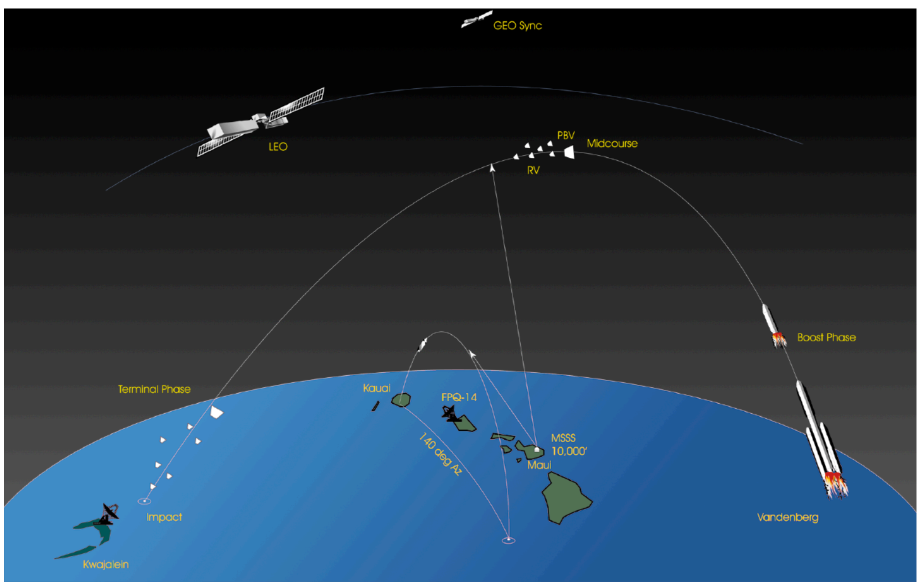


Figure 1-1. Favorable Geographic Location of AMOS

Operation and maintenance of MSSS, subsystem integration, and modification of existing subsystems are the primary responsibilities of Rocketdyne Technical Services (RTS), a Boeing Company. Additional RTS responsibilities include mission planning, scheduling, and the reduction, interpretation and analysis of data recorded at MSSS.

The main field office building at the Maui Research and Technology Park in Kihei, Maui, Hawaii, includes optical and electronic laboratories, data processing, and administrative functions. Detachment 15, Air Force Research Laboratory and Detachment 3, 18th Space Surveillance Squadron (SPSS) are Air Force offices located in the same building. Purchasing, shipping, and receiving functions are located in nearby Kahului, Maui.

The Air Force Materiel Command's Air Force Research Lab Directed Energy Directorate, Kirtland Air Force Base, New Mexico, sponsors the AMOS Program. The objectives of the AMOS Program are to:

- Provide state-of-the-art measurement support to various government agencies and the scientific community for research and development programs;
- and serve as a test-bed for newly developed evolving electro-optical sensors.

AMOS consists of the observatory's premier optical instrument, the 3.6-meter telescope, the sensors mounted on it, the 1.6-meter telescope, the 1.2-meter telescope, the 0.8-meter, the 0.6-meter, and the 0.4-meter Raven telescopes. These assets are detailed in Section 3. The sensors are described in detail in Section 4. The primary mission of these telescopes is to track man-made satellites while recording their orbital parameters (metrics), radiation properties (signatures) and forming images for space object identification.

Contiguous with MSSS is the Ground-based Electro-Optical Deep-Space Surveillance (GEODSS) facility, a three-telescope operational system with computer support that provides a capability to look into deep space, 3,000 to 23,000 miles (4,800 km to 37,000 km) where many communication, weather, and surveillance satellites orbit. The three telescopes have approximately 1 meter apertures and adjustable fields-of-view from 1° to 2°. For the purposes of this User's Manual, GEODSS will be considered a separate facility.

Requests for Support

Requests for AMOS support should be directed to:

AMOS Program Office
Detachment 15, Air Force Research Laboratory
535 Lipoa Parkway, Suite 200
Kihei, HI 96753
(808) 874-1541

Initial contact with AMOS should be made through the AFRL/DEBI Visiting Experiments Programs Manager at (808) 874-1541. Requests for access to AMOS program information and/or visits to the MSSS should be processed through AFRL/DEBI.

Section 2 - SITE DESCRIPTION

Site Description

Site History

The evolution of the Maui Space Surveillance System demonstrates several stages in the history of space object tracking telescopes. The oldest designs still in use are the 1.2-meter dual telescopes and the 1.6-meter telescope. A modern 3.6-meter telescope, the Advanced Electro-Optical System (AEOS) is on line with various sensor packages in acceptance testing.

The designers of the Maui 1.2-meter and 1.6-meter telescopes selected the German style equatorial mount. Placing them on azimuth turntables provided a third axis to enable easier tracking of objects that orbit in planes other than the Earth's equatorial plane. Sensors that detect light collected by these telescopes are mounted on the telescope body itself and must be remotely controlled.

The Laser Beam Director (LBD) was developed to illuminate and image dark sky objects. The LBD is a semi-fixed 0.6-meter aperture beam expander telescope looking into a tracking flat. Heavy equipment, such as the multi-stage Korad ruby laser, resides in a room below next to the concrete pier that supports the telescope. The tracking flat swings through its range of motions unencumbered by instruments and cables.

The 0.8-meter Beam Director Tracker (BD/T) is an afocal beam expander on an elevation over elevation mount, using mirrors to relay the beam through large hollow bearings and out to the laser rooms on either side of the telescope mounting pier. There are two telescope mirrors in the standard afocal pattern plus six optical flat mirrors. Three flats are hidden within the structure of the telescope. No major instrumentation hangs on this telescope frame. The unencumbered frame pivots in an elongated gimbal having a hollow box-like structure containing the hidden mirror mounts. This gimbal-box pivots at each end. The two sets of pivots allow the telescope access to most of the sky, except for east and west azimuths, where the lowest elevations are about 30^{o} due to a GEODSS dome to the east and the gimbal bearing to the west.

The latest addition to the MSSS array of telescopes is the 3.6 meter Advanced Electro-Optical System (AEOS). The AEOS provides extensive observation, measurement and analysis capabilities through a state-of-the-art sensor suite that permits photometry, radiometry, spectrometry, and compensated imaging in the visible and infrared spectra.

AEOS user opportunities were primary considerations in both the facility and optical system designs. The optical system provides the flexibility of mounting special-purpose user sensors at multiple locations. Seven experiment laboratories are provided with IRIG timing, video and data services support.

Site Characteristics

The observatory (referenced to the point on the azimuth axis which is at the height of the intersection of the polar and declination axes of the 1.2-meter telescope mount) is located at a geodetic altitude of 3058.2-meters, close to the crest of the dormant volcano Haleakala at:

- latitude 20:42:30.5 (20.7084)° N
- longitude 156:15:28.7 (156.2578) ° W

This site provides a relatively stable climate of dry air characterized by low levels of particulate matter and minimal scattered light from surface sources. The astronomical seeing for the site reflects the exceptional nature of the location. Based on double star observations, seeing is typically on the order of one arc second. Measurements of Fried's atmospheric turbulence coherence length, (r_o), exclusive of "dome seeing" (phase shifts due to internal and external temperature differences), indicate a 12 cm average value during the summer, with winter values averaging 10 cm. A program is currently underway to significantly reduce dome-seeing effects.

Weather and Atmospheric Statistics

The weather on Maui is dominated by northeasterly trade winds of 10-25 mph. Trade winds are generated by a series of high pressure anticyclones and ridges which persist 300-500 miles north of the islands. A trade wind inversion normally traps marine moisture and haze well below the site, so the MSSS is characterized by dry, clear air with visibility exceeding 150 km.

From late November through April the highs and their associated ridges periodically break down or are pushed south by low-pressure systems moving through the North Pacific toward the North American mainland. Fronts and troughs associated with these lows are primarily responsible for Maui's rainy season. Another component of the rainy season is the "Kona" (Hawaiian for leeward side) storm, generated when high pressure centers move south of the islands and the winds turn southerly bringing moisture north from the subtropical convergence zone. From July through October, occasional rain and storms are associated with the remnants of hurricanes and tropical storms originating off southern Mexico. These storms typically dissipate to the east of Maui, but a hurricane actually reaches the islands every 5-10 years. Average rainfall at the site is about 15 cm/month during the winter and spring months (November-April) and about 5 cm/month in the summer and fall months (May-October). Light snowfall occurs at the site 2-3 times each winter with maximum accretions of 7 inches observed.

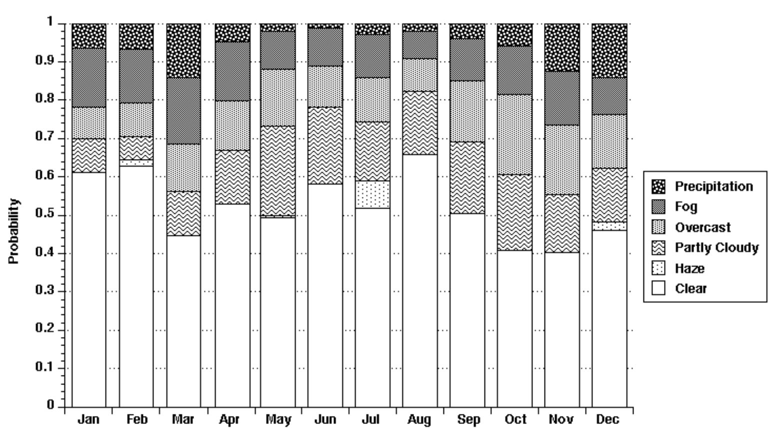


Figure 2-1. AMOS Weather Observations, 5-yr Average

Summary of Weather Observations

Figure 2-1 shows a summary of site weather observations over the period 1986 through 1991. These observations are for the dusk-to-dawn observational time. The site does not operate under precipitation, fog, overcast (>80% sky cover), or excessive wind conditions. The combination of these factors produces a monthly average of 60% operational time in winter and spring and 70% during summer and fall. Clear weather in the figure refers to spectroscopic sky quality. Photometric sky quality data are not currently available.

Temperature

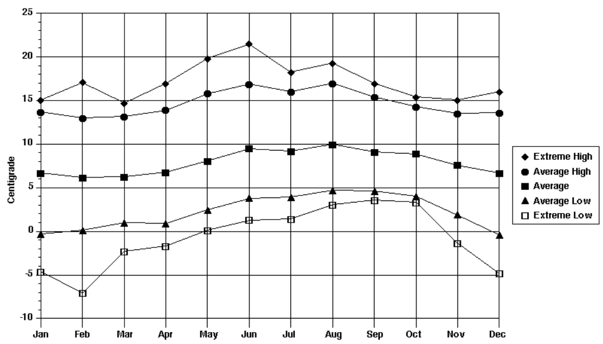


Figure 2-3. AMOS Monthly Temp, 5 yr. Average

Figure 2-3 shows the average monthly temperature at the MSSS along with the average and extreme monthly highs and lows for the 1986-1991 period. The five year average diurnal temperature swing is 5.8° Celsius with an afternoon high at 2-4 PM and an early morning low at 5-7 am, HST. The average site relative humidity is about 45%. A frequent afternoon peak in relative humidity results from anabatic winds that carry moisture upslope from below the tradewind inversion. These winds subside and the relative humidity drops quickly as dusk approaches. Extended periods of 5-20% relative humidity are not uncommon. This, combined with the 710-mbar average barometric pressure, should be considered in the design of electronic equipment for use at the site.

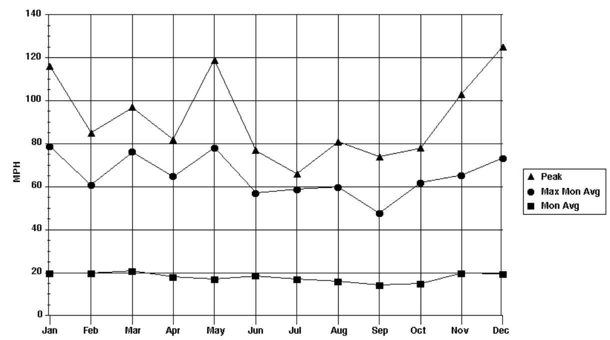


Figure 2-2. AMOS Windspeed, 5 yr. Average

Wind Information

Figure 2-2 shows the monthly average, maximum hourly average, and peak wind speed for the site and Figure 2-4 shows the average monthly wind direction. While most periods of high winds occur during winter storms, winds over 50 mph can occur at any time.

Seeing

Seeing data is derived from stellar image size measurements on both the 1.6-meter and 1.2-meter telescopes. The average effective zenith r_0 at a wavelength of 500 nm for the 1.6-meter system is about 6 cm in the winter and 7 cm in the summer. The 1.2-meter seeing averages about 8 cm with a slight peak in June. Recent measurements suggest that the difference in effective r_0 for the two systems is largely due to differences in dome seeing degradation. Exclusive of dome seeing, the site can produce averages of about 10-cm in the winter and 12-cm in the summer. A program is currently underway to reduce the dome seeing effects. More detailed atmospheric data is available on request.

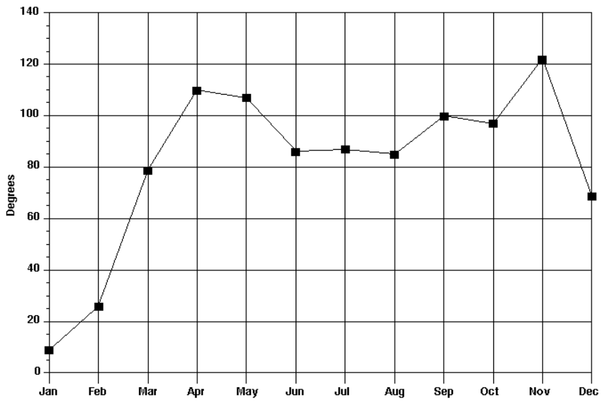


Figure 2-4. AMOS Wind Direction, 5 yr. Average

Atmospherics Instrumentation

Meteorological data is collected and archived at 3-minute intervals 24 hours/day. Standard data include wind speed and direction (two sensors), temperature, dew point, and barometric pressure. A visibility monitor was added to the suite of instruments in the winter of 1992. Seeing measurements also can be obtained from stellar image size measurements on the telescope systems. More information about atmospheric instrumentation is available.

Observatory Facilities

As shown in Figure 2-5 the MSSS consists of a main building interconnecting the two large domes (east and west) and two small domes (north and south), three GEODSS domes, and the AEOS facility housing the 3.6-meter telescope. The main building includes office and workspaces, an operations control and computer facility, a secure communications facility, optical and electronics laboratories, a briefing room, and kitchen facilities. The east dome contains a 1.6-meter diameter aperture telescope while the west dome houses two 1.2-meter diameter telescopes on a common mount. The south dome contains the 0.6-meter Laser Beam Director (LBD) and the north dome houses the 0.8-meter Beam Director / Tracker (BD/T). Telescopes are described in another chapter of this manual.

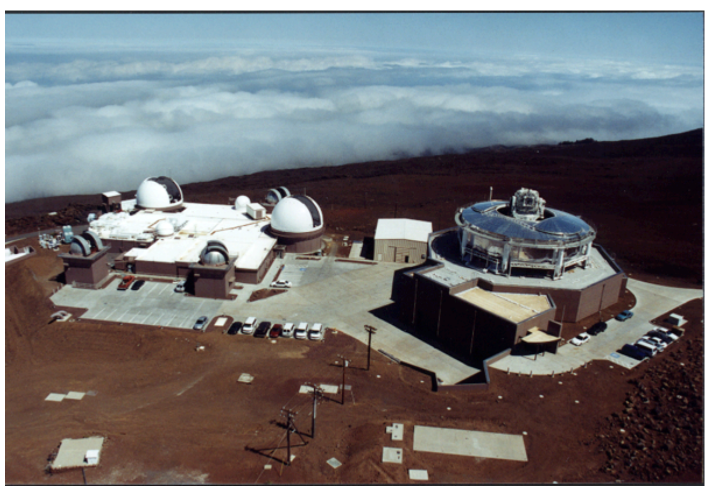


Figure 2-5. AMOS/MSSS Site Layout

The technical support building provides additional office space and storage area. Additional support equipment includes a 1.6-meter diameter optical flat, a water collection system, and a laser cooling system.

Endoatmospheric Studies

Ideally situated for full-scale endoatmospheric studies with aircraft, drones, and cooperative instrumented aircraft test beds, the site has direct visual access into over 30,000 square miles of Special Operating Areas (SOAs).

SOA assignment and use is coordinated by AMOS for the VE with the controlling agency, the U.S. Navy Fleet Area Control and Surveillance Facility (FACSFAC), located on Ford Island, in Pearl Harbor, Oahu. In practice, the SOAs are reserved for specified periods for either shared or exclusive use, depending on test constraints and military training requirements. They can be extended through special agreements with the FAA to approximately twice their areal extent to encompass tests requiring very long path (up to 300 miles) observations. Cooperative aircraft are typically controlled directly by AMOS personnel after they enter the SOA.

Sources of Aircraft Targets

Owing to the proximity of MSSS to several aircraft operating bases and training ranges, a wide variety of fixed and rotary wing tactical and support aircraft can be routinely accessed for cooperative and non-cooperative experiments. Services can be obtained at no cost in most cases, if it can be demonstrated that test requirements, flight profiles, etc. are relevant to unit training goals of the participating aircraft operating units.

Measurement Scenarios

The suitability of the site for endoatmospheric studies derives from its unique location and support infrastructure for electro-optical surveillance. Applying well documented and verified scaling laws, valid tests and measurements can be supported in thermal imaging, atmospheric transmittance, clutter phenomenology including detection, and sensor performance evaluation. A broad range of challenging test requirements involving advanced simulations in these areas can be satisfied with a suite of active and passive radiometric and imaging sensors which can be brought to bear on low elevation targets. Alternately, a visiting experimenter supplied sensor or system can be hosted within the observatory complex (providing power, water, communications, engineering assistance, and shelter), or at selected remote field test sites on the mountain.

Field Office

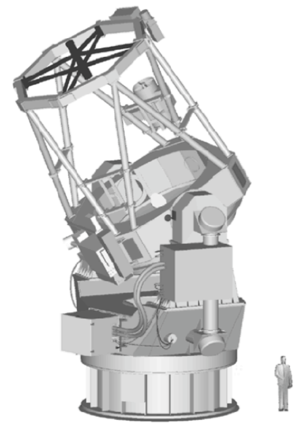
Management, administration including security, planning, certain data reduction and analysis tasks, engineering, drafting, software development, microprocessor and digital development, and most logistic functions are performed in a field office facility located 80 feet above sea-level near the town of Kihei. The AMOS field office is a 20-minute drive from the Kahului Airport and approximately 49 miles (80-90 minutes) from the summit of Haleakala. Meetings with visitors, potential users, and other interested groups can be held in the conference room. Teleconferencing, available between the field station and the observatory may enhance such meetings by microwave link. Figure 2-6 is a photograph of the field office, Premier Place, with the MHPCC to the right and Haleakala rising to 10,000 feet in the background.

Figure 2-6. Premier Place with Haleakala Backdrop

Section 3 - TELESCOPES AND MOUNT CONTROL

Telescopes

Observatory hardware systems include the major telescopes, their mounts and domes, the laser beam director (LBD), the beam director tracker (BD/T), Raven, and their computer systems. The sensor systems associated with each telescope are described in Section 4. The timing system, the communications system, the video systems and other support systems, including special software, are discussed in Section 5. The 3.6-meter telescope is pictured in Figure 3-1, the 1.6-meter telescope is pictured in Figure 3-4 and the 1.2-meter telescopes are pictured in Figure 3-5. Optical specifications of the telescopes are tabulated in Table 3-2.



The 3.6-meter Telescope

The AEOS Telescope includes an elevation over azimuth gimbal assembly (i.e., an azimuth base and an elevation yoke) as shown in Figure 3-1. The telescope gimbal can slew up to 18 degrees per second in azimuth and 4.75 degrees per second in elevation. The support structure for the mirror elements consists of a trunnion box, a truss, and a headring. The truss and headring support the secondary mirror and two acquisition telescopes. The trunnion, which swings in the yoke to provide elevation change, supports the primary mirror cell, the tertiary mirror, a wavefront sensor, and up to three other sensor packages. The tertiary mirror directs the optical beam to any of the four trunnion ports or to one of two Nasmyth ports. One of the Nasmyth ports initiates a coudé path to the adaptive optics (A/O) system and visible imager located beneath the telescope. The A/O system provides the input to the AEOS visible imager or directs the beam into one of seven optics labs located on the facility's first floor as shown in Figure 3-2.

Figure 3-1. The 3.6-meter Telescope

The primary and secondary mirrors provide a 726-meter focal length, f/200 Cassegrain configuration with a full field-of-view (FOV) of 300 µrad for the coudé path. An alternate secondary mirror can be used which provides a full FOV of 1000 µrad for trunnion-mounted sensors. The primary mirror was figured and polished to a root-mean-square (rms) accuracy better than λ/10 (tilt, focus and astigmatism) removed from a 3.67 meter meniscus blank with a maximum center thickness of 16 centimeters. In order to compensate for gravitational sag during operations, the figure of the primary mirror is actively controlled by 84 axial and 48 radial actuators and a mirror figure sensor which operates as part of pre-mission calibrations. The clear aperture diameter of the primary mirror is 3.63 meters, with 6% obscuration.

AEOS Sensor Suite

The AEOS Sensor Suite comprises three resident sensors: the Radiometer, the LWIR Imager and the Visible Imager.

Table 3-1 describes these three mission sensors, as well as the acquisition sensors.

Table 3-1. AEOS Sensor Suite Specifications

			Tertiary Mirror Position				
	Acquisition		Trunnion			Coudé	
	LFAT	LAAT	Radiometer			LWIR Imager	Visible Imager
Aperture (cm)	20	58	363			363	363
Spectral Range [(1)] (µm)	0.4 - 0.9	0.4 - 0.9	0.4 - 1.0	2 - 5.5	8 - 14 17 - 23	8.3 - 9.2 10.1-12.9	0.7 - 1.1
Detector (Pixel) FOV (µrad)	94	16 / 4.4	2.0	1.5	2.0	0.73	0.1 / 0.23 / 0.6
Field of View (µrad)	2.7 Deg	0.125 / 0.050 Deg	256	192	256	146	51 / 120 / 300
Detector Type	ICCD	ICCD	Array	Array	2 Arrays	2 Arrays	Array
Array Size (Pixels)	512^2	512^2	128^2	128^2	128^2	$>200^2$	512^2
Max Frame Rate (FPS)	RS-170	RS-170	500	60	200	60	>5
Detector Material	Gen III ICCD	Gen III ICCD	Si	InSb	Si:As	Si:As	Si
Operating Temp.			-40°C	70K	10K	10K	-40°C

[(1)] Filter wheels allow for sub bands
Does not include A/O sensors

AEOS Dome

The AEOS observatory dome retracts to completely expose the telescope. This, together with the telescope gimbal design, provides viewing over the full 2π steradians above the gimbal axes, plus lookdown to 5 degrees below the horizon for all azimuth angles. This design also avoids the jitter associated with a traditional rotating clamshell dome, reduces/eliminates in-dome turbulence effects, and permits higher slew rates in support of the SOI mission.

AEOS Facility

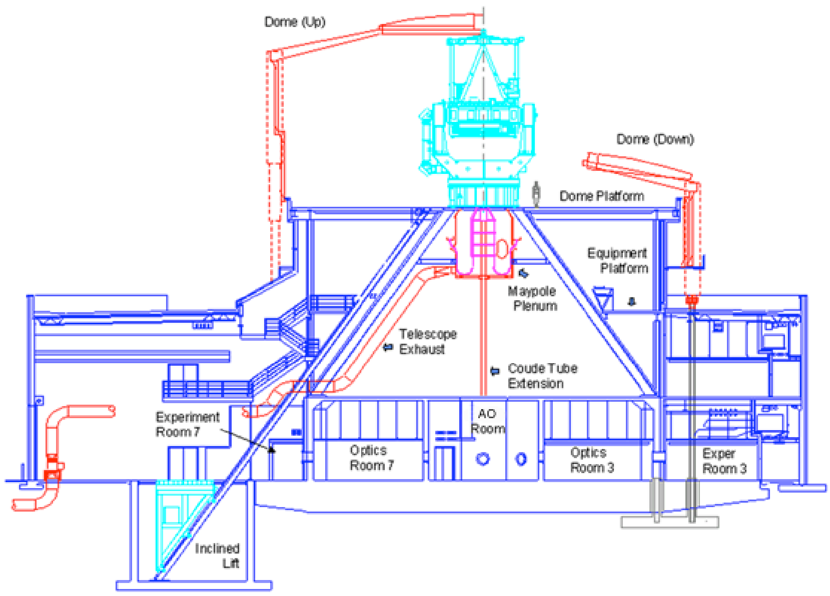


Figure 3-2. AEOS Facility Cross-Section

The AEOS facility provides support for the telescope, and includes a room, located directly below the telescope to house the adaptive optics system, and seven laboratory suites, each consisting of an optics room and an experiment room.

The optics rooms are located around the circumference of the building. The optical beam can be directed into any one of the seven rooms. The purpose of the multiple rooms is to allow one user to perform operations in one lab while another user is setting up equipment in another. Each optics room has an associated experiment room for additional instrumentation and control. The optical beam can also be directed through the optics room into the experiment room. A control room, which is located on the second floor of the facility, houses operator control stations for all the AEOS sensors and the telescope.

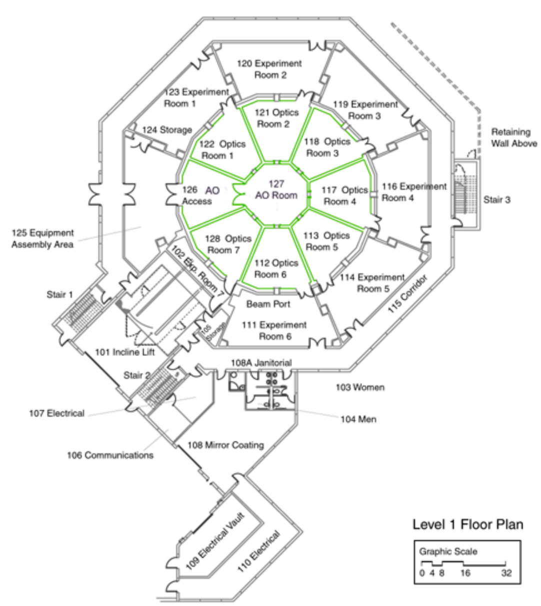


Figure 3-3. AEOS Coudé Lab Layout

The 1.6-meter Telescope

A major asset of the MSSS is the f/16 1.6-meter telescope (Figure 3-4), one of the finest optical instruments of its size in the world. This closed-tube, Cassegrain system consists of near diffraction-limited (_/25 rms wavefront error at 632.8 nm) optics installed on a high-performance mount. The telescope has a 1.6-meter clear aperture, a Cassegrain focal length of 25.00 meters (984 inches) and a plate scale of 8.25 arc seconds/mm at the Cassegrain focus.

Figure 3-4. The 1.6-meter Telescope

The 1.6 meter telescope has both rear and side instrument mounting surfaces. The rear Blanchard surface has a 19-inch instrument working distance and is capable of handling instrument packages weighing up to 1500 pounds. The side (folded Cassegrain) Blanchard surface has a 13-inch instrument working distance and can accommodate packages weighing up to 500 pounds. The telescope must be statically rebalanced every time there is a change in the mass or positioning of the attached instruments.

The 1.6-meter telescope is installed on a high performance three-axis mount. The mount is a standard astronomical equatorial arrangement carried on an azimuth turntable and rests on massive vibration-isolated concrete piers. Tracking is done in the polar and declination axes with the azimuth turntable set to a fixed position optimized for the track. All three axes are driven by torque motors and ride on hydraulic bearings. Mount position is derived from 23-bit shaft-angle encoders having a least significant bit equivalent to 0.15 arc seconds.

Stellar observations can be made at any azimuth but are normally performed with the azimuth axis set to align the polar axis to true north. The mount is then used as a classical astronomical mount, with the declination axis fixed and the polar axis rotating at the sidereal rate to perform the track.

Tracking of orbital and sub-orbital targets is usually performed with the azimuth angle set to point the polar axis 180 degrees from the azimuth at which the object culminates (culmination occurs at the highest elevation angle reached by the object on the pass). Most of the tracking motion then takes place about the polar axis with only small angular motions in the declination axis.

Mount capabilities include angular accelerations to 2 degrees/sec^2 and angular tracking velocities to 3 degrees/sec under ideal conditions (early acquisition, bright test object, away from sun or moon). Absolute pointing accuracy to within 2 arc seconds rms, and tracking accuracy to within 1 arc second rms can be achieved.

Focusing is accomplished by moving the secondary mirror (i.e., changing the inter-mirror spacing), under computer control. The mount control computer automatically corrects focus in real time while tracking satellites using calculated range.

Excellent primary mirror support (airbags for axial support and a mercury belt for radial support) results in an instrument that maintains its static figure performance over all relevant mount attitudes. Invar metering rods installed between the primary and secondary mirrors minimize changes in the distance between the two mirrors due to thermal expansion. Safety clips have been added to allow depression down to 5^{o} below horizontal without danger to the telescope.

The 1.6-meter telescope uses the dual-aperture AMOS Acquisition Telescope System shown in Figure 4-22. The optical characteristics of the major AMOS telescope systems are summarized in Table 3-2.

By inserting a reflecting tertiary mirror, light from the telescope is diverted through the side Blanchard instrument mounting surface instead of the rear Blanchard. The side Blanchard surface carries the recently upgraded GEMINI Visible/IR sensor; the AMOS Spectral Radiometer (ASR), and the Platinum Silicide (PtSi) Array have been removed. With the tertiary withdrawn, the rear blanchard can be used. The AMOS Acquisition Telescope System (AATS), with its own telescopes is mounted on the outside of the main telescope tube and is shown in Figure 4-22.

The 1.6-meter Dome

The 1.6-meter dome has a pair of long split doors that open beyond zenith. The dome and mount have rotation and acceleration capabilities which permit continuous tracking of rapidly moving orbital and sub-orbital vehicles.

The dome is fully automated to maintain dome-slot alignment for any telescope pointing.

Dome Automation

The dome automation system for the 1.6-meter telescope allows operation of the telescope from the main control console located in the MSSS Space Operations Center (SOC). This system also provides remote control of the telescope hydraulic functions and the tertiary mirror. The dome can be moved manually or can be set to track the telescope automatically, based on the effective pointing azimuth of the telescope. A mount safety system provides both warning and automatic stopping of any telescope axis based on a lookup table of safety stops. A TV surveillance system provides both day and night monitoring of the telescope for equipment and personnel safety.

The 1.2-meter Telescope

The dual 1.2-meter telescopes (Figure 3-5) are mounted on opposite sides of a single polar axis and are fixed to a common declination axis. Both of these major telescopes are open-tube, classical Cassegrain optical systems having parabolic primary mirrors and hyperbolic secondary mirrors. Both have Invar metering rods installed between the primary and secondary mirrors to minimize thermally induced changes.

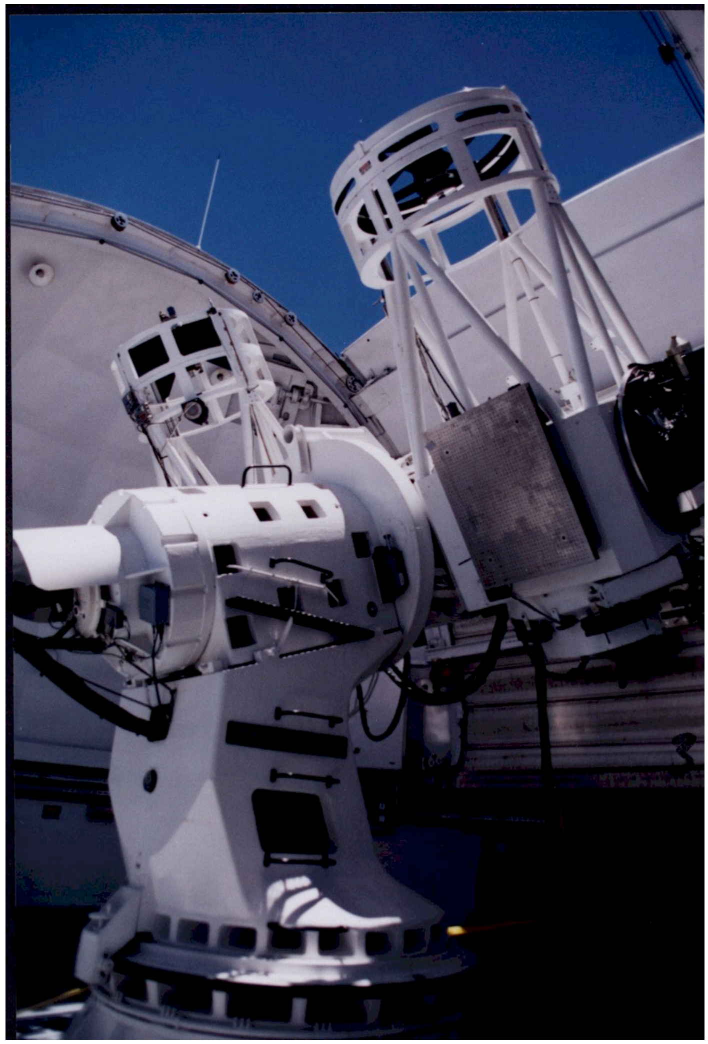


Figure 3-5. The 1.2-meter Telescopes

One telescope has a 29-inch back focal distance and is thus known as the B29. This telescope has a single Blanchard instrument-mounting surface (named for the Blanchard surface grinder), at the rear of the telescope, with an 11-inch instrument working distance (distance beyond the Blanchard mounting surface to the focal plane). All the Blanchard surfaces are centrally perforated to allow the light to pass through to the focal plane. The B29 has a relative aperture of f/20, a focal length of 24.59 meters (968 inches), and a plate scale of 8.4-arc seconds/mm. It is used primarily for Long Wave InfraRed (LWIR) and photometric data collection. The B29 telescope is located on what would normally be the counterweight side of a standard equatorial mount. It is equipped with a toggling secondary mirror that is used with the Contrast Mode Photometer (CMP) and the infrared radiometer known as AMTA, both detailed in Section 4. Its optical performance in the visible is two times the diffraction limit.

The other 1.2-meter telescope has a 37-inch back focal distance and thus is known as the B37. The B37 has a relative aperture of f/16, a focal length of 19.83 meters (781 inches) and a plate scale of 10.4 arc seconds/mm at the Cassegrain focus. This telescope has two Blanchard-ground instrument mounting surfaces, one at the side, and one at the rear. Both have 19-inch instrument working distances. A 45° folding mirror between the primary and secondary mirrors directs the telescope beam to the side or lets it pass through the rear Blanchard surface. The position can be switched in a few seconds. The B37 telescope is normally used for low-light metric tracking using the Low Light Level TV camera (LLLTV), located within the MOTIF Advanced Imaging System (MAIS) sharing the rear Blanchard with the MAIS imaging camera. In the visible wavelengths, the B37 optical performance is three to four times the diffraction limit. A side Blanchard surface is available for use by visiting experimenters.

The pair of 1.2-meter telescopes is installed on a high performance three-axis mount. The mount is a standard astronomical equatorial arrangement carried on an azimuth turntable, and rests on massive vibration-isolated concrete piers. Tracking is done in the polar and declination axes with the azimuth turntable set to a fixed position optimized for the track. All three axes are driven by torque motors and ride on hydraulic bearings. Mount position is derived from 23-bit shaft-angle encoders having a least significant bit equivalent to 0.15 arc seconds.

Stellar observations can be made at any azimuth but are normally performed with the azimuth axis set to align the polar axis to true north. The mount is then used as a classical astronomical mount, with the declination axis fixed and the polar axis rotating at the sidereal rate to perform the track.

Tracking of orbital and sub-orbital targets is usually performed with the azimuth angle set to point the polar axis 180 degrees from the azimuth at which the object culminates (culmination occurs at the highest elevation angle reached by the object on the pass). Most of the tracking motion then takes place about the polar axis with only small angular motions in the declination axis.

Mount capabilities include angular accelerations to 2 degrees/sec^2 and angular tracking velocities to 3 degrees/sec under ideal conditions (early acquisition, bright test object, away from sun or moon). Absolute pointing accuracy to within 2 arc seconds rms, and tracking accuracy to within 1 arc second rms can be achieved.

Each 1.2-meter telescope has a primary mirror support system that incorporates three air bags for axial support and a mercury belt for radial support. Simultaneous boresighting of the two optical systems is accomplished by means of a beam steering system that drives the B37 secondary (strabismus or "wall-eyed" correction). The B37 secondary is tilted to "bend" the optical axis of the B37 to maintain parallelism with the B29 telescope. Data for the strabismus correction is contained in the computer Mount Model (MM) and is calibrated using stellar observations. Mount Models are discussed in section 3.

Mounted alongside the B29 telescope is the dual-aperture MOTIF Acquisition Telescope System (MATS), with three switch-selectable fields of view and projection reticles, shown in Figure 4-22.

The 1.2-meter Dome

The 1.2-meter dome has a pair of long split doors that open beyond zenith. Both mounts and dome have rotation and acceleration capabilities, which permit continuous tracking of rapidly moving orbital and sub-orbital vehicles.

The dome is fully automated to maintain dome-slot alignment for any telescope pointing. The dome enclosing the two 1.2-meter telescopes has a wide slot so that both telescopes can be used simultaneously with no vignetting.

Dome Automation

The dome automation system for the 1.2-meter telescope allows operation of the telescope from the main control console located in the MSSS Space Operations Center (SOC). This system provides remote control of the telescope hydraulic functions. The dome can be moved manually or can be set to track the telescope automatically, based on the effective pointing azimuth of the telescope. The mount safety system provides both warning and automatic stopping of any telescope axis based on a lookup table of safety stops. A TV surveillance system provides both day and night monitoring of the telescope for equipment and personnel safety.

The BD/T Telescope

The Beam Director/Tracker is a versatile, multipurpose system that can expand a laser beam by a factor of five up to 0.82-meters (32 inches), and direct it to illuminate the object being tracked. It is designed to accept up to a six-inch beam through a coudé path to be expanded and propagated from the telescope. The BD/T is installed in a clam shell 16 foot dome (Figure 3-6). The BD/T can also project a beam without expansion by means of a retractable diagonal mirror. An acquisition telescope with a video camera, the 1.2^{o} FOV BD/T Acquisition Telescope System (BATS), is attached to the side of the telescope.

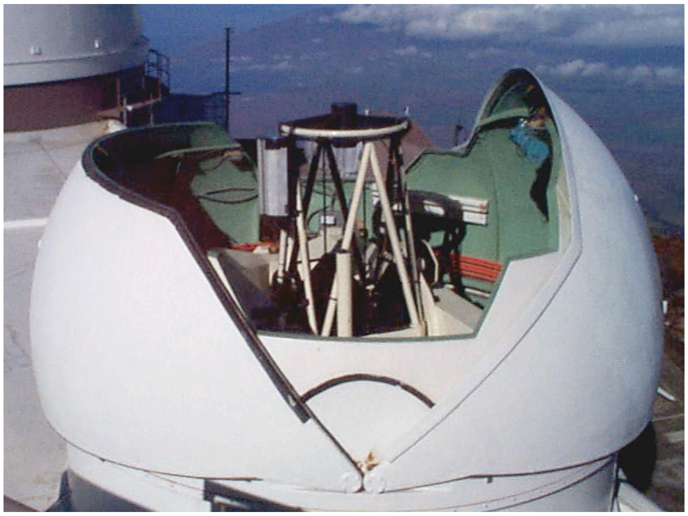


Figure 3-6. The BD/T Telescope and Dome

The BD/T, built by DFM Engineering, Inc., is a standard open tube afocal beam expander telescope with a 0.82-meter concave paraboloid f/2.9 primary mirror and a 0.18-meter convex paraboloid f/-2.8 secondary mirror. There are Invar spacers between the primary mirror cell and the ring supporting the secondary. This provides passive spacing compensation for temperature changes. A total of eight mirrors (primary optics and coudé path) are used and each mirror is aluminum coated (except for the tertiary, see below). All mirror alignments are optically centered, on-axis, to minimize coning of the beam path as the telescope swings through its range of motion.

A coudé path (Figure 3-7) redirects light received by a telescope to a fixed point in the observatory by a series of elbow bends, permitting instrumentation to remain stationary. This telescope can be used to direct the beam from a stationary source outward to the object being tracked. The additional mirrors required, however, result in decreased transmission through the system.

There are three configuration options for the BD/T on-axis tertiary. One option is a specially coated tertiary that provides 50% reflection to the coudé path. The remaining light can be sent to a boresight telescope of Cassegrain design that focuses the collimated light from the secondary. At this focus an RCA ISIT (intensified silicon intensifier target) video visible wavelength camera is installed. With the boresight telescope and the main telescope in combination, this becomes an 0.8-meter diameter telescope. With filtering to reject the laser wavelength at the camera, video output is available while a laser beam is projected. Figure 3-8 shows the general appearance of the BD/T.

The second option is installation of a totally reflecting (overcoated aluminum) tertiary mirror. In this case the boresight camera is not effective and BATS can be used for acquisition and tracking if necessary. A laser beam for propagation originating in room 44 or 72, can be pre-expanded to 15 cm in diameter

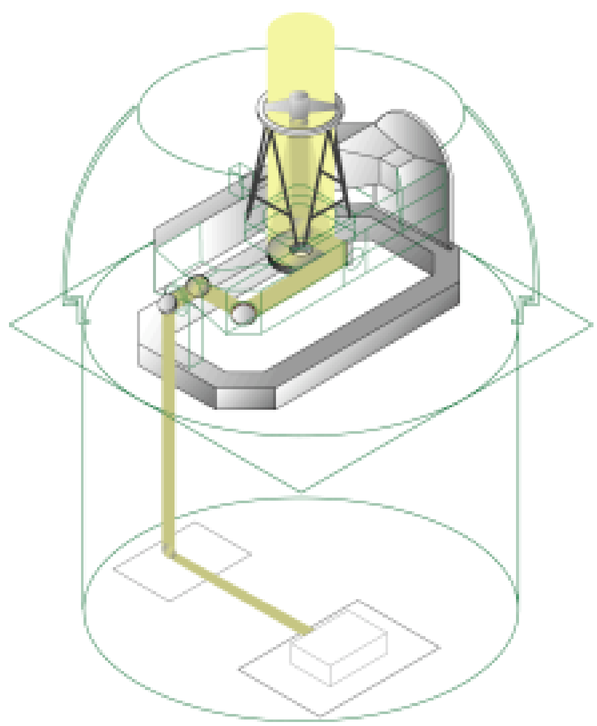


Figure 3-7. The BD/T Telescope Coudé Path

corresponding to an expansion ratio of 5 when it is emitted from the 0.8-meter aperture.

A third option is removal of the tertiary to allow use of the telescope with instruments mounted on the Blanchard plate behind the primary. As in the first option, a Cassegrain telescope is used to focus the collimated light from the secondary.

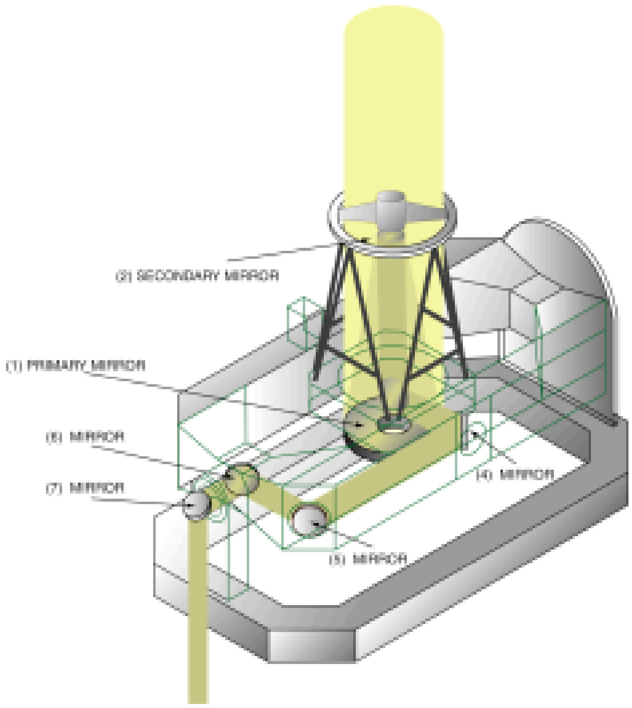
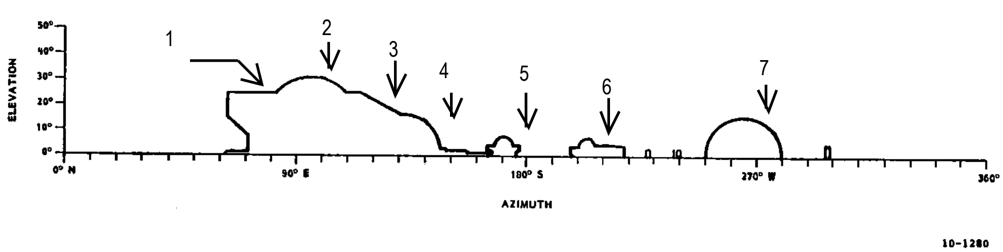


Figure 3-8. The BD/T Telescope Gimbal

The BD/T has two optical configurations in addition to the changes of the tertiary mirror. The first configuration expands the beam as described above. The 15 cm coudé beam bundle originates in room 44 or 72, horizontally and is projected eight inches on-center over the top of one of two standard 4' X 8' Newport optical tables. The tabletops are magnetic stainless steel with 1/4-20-thread screw holes, one inch between centers, with one line of holes on the optical axis. The table has a cone fixture for precision alignment of a removable telescope (Taylor-Hobson or K&E Brightline). This telescope is used to establish an optical axis reference within arc seconds.

The second optical configuration in the BD/T allows a projected beam to bypass the primary optics and maintain the original size from the laser output. This is accomplished by using a folding flat to intercept the coudé light path before the laser beam reaches the tertiary and then projecting the beam parallel to the axis, past the secondary mirror, avoiding the secondary support. Other than the annulus obscuration, real-time bore-sight video is not impacted by either configuration unless the fully reflective coated tertiary is in use.



1 SAFETY RAIL
2 GEODSS TOWER #3
3 TRAILER (BD/T
4 1.6 m DOME
5 GEODSS TOWER #2
6 GEODSS TOWER #1 W/ LBD TRAILER
7 1.2 m DOME

Figure 3-9. Panoramic View from AMOS BDT

The main BD/T mount structures (gimbal and base) are welded, stress relieved, hot rolled steel plate. The BD/T mount is an altitude over altitude gimbal. This mount configuration allows the system to easily track objects that pass through zenith. Since the horizon is limited by roof obscuration to the east and west (Figure 3-9), the major axis is oriented east to west and the minor axis is oriented north to south. This orientation allows tracking down to 20 degrees from the horizon in the north and south and down to 30 degrees from the horizon in the east and west.

Mount capabilities include tracking velocities up to **3^{o}/sec under ideal conditions** (early acquisition, bright test object, away from sun or moon) and angular accelerations up to $4^{o}/sec^{2}$. Variations from the track are within 1 arc second rms.

The BD/T can track near-Earth objects either simultaneously with or independently of any or all of the other mounts. The BD/T can be operated with a variety of lasers in conjunction with sensors on the other MSSS prime telescopes for space object illumination of selected targets. The installation is designed to accommodate user agencies' lasers mounted in an adjacent area and to use the existing optics and pointing system to conduct measurement programs tailored to a specific laser system.

LBD Telescope

The Laser Beam Director combines a 0.64-meter (25 inch) Mersenne (afocal) beam expander and a 0.91 meter (36 inch), gimbaled tracking flat to provide precise laser beam pointing and tracking. The LBD is housed in a 16-foot clam shell dome on the southwest side of the MSSS facility. The primary mirror cell and the assembly supporting the secondary are mounted horizontally on two sets of Zerodur bars. This provides extremely low focus drift due to changes in temperature. The system is mounted on an azimuth turntable, which is positioned in 15° increments and locked prior to a tracking operation.

The beam is projected up through the center of the azimuth table to the LBD, where all tracking is then done in the azimuth and elevation axes by the lightweight, gimbaled tracking mirror. The LBD is capable of pointing the laser beam across a range of 95° in azimuth and from 15° to 95° in elevation without repositioning the azimuth table. It will project the beam within a pointing error of approximately 2 arc seconds rms. Figure 3-11 shows the major components of the LBD. Figure 3-10 is an optical diagram of the LBD and its coudé path.

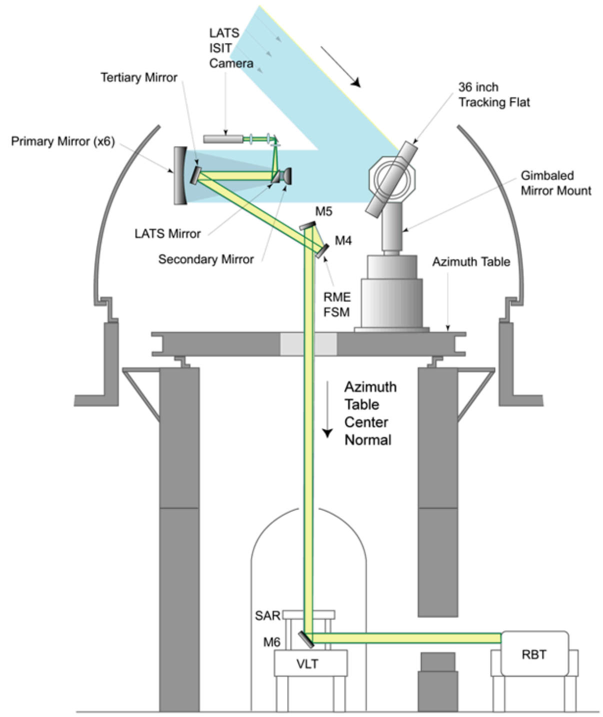


Figure 3-10. The LBD Telescope Coudé Path

The LBD Acquisition Telescope System (LATS) was a feature added in 1995. A motorized 45° flip-in secondary was installed in front of the Mersenne secondary which essentially converts the LBD into a full aperture Newtonian telescope when the flip-in flat is inserted. While the LATS configuration prevents laser projection with the flip-in inserted, this modification has allowed replacement of the dichroic tertiary mirror with a high reflector.

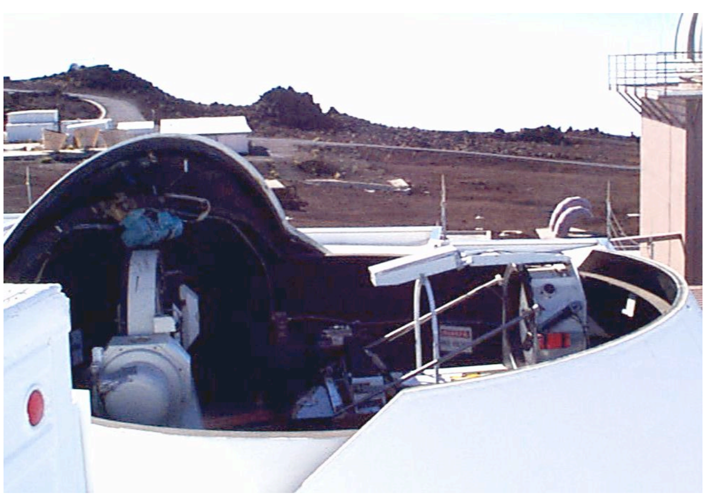


Figure 3-11. The LBD Telescope and Dome

The beam director, together with a laser, can be used in conjunction with other sensors on the MSSS prime telescopes for space object illumination and to provide range information on selected targets. In addition, the LBD is designed to enable user agencies to mount their own laser in the sub-dome area and use the existing optics and pointing capability to conduct measurement programs tailored to a specific laser system.

Raven Telescope

Raven-class telescopes are small, commercially-available telescopes, one of which is used operationally at MSSS in support of the satellite metric observations. The operation is autonomous: the telescopes open at sunset, make observations and reduce the data automatically, and close at sunrise. The telescopes are supported by a weather-monitoring system, which safeguards the telescope in the event of inclement weather. The AMOS Raven telescope uses a 512 x 512 x 24μ CCD camera on a 37 cm (14.5 inch) diameter telescope. This configuration has a field view of 0.8 degrees square, with a pixel size of 4.4 arcseconds. Limiting magnitude is approximately $M_V = 17$ for a 20 second exposure. Because the system is based on commercially-available equipment, the individual components, such as the camera or telescope may change as new and better hardware and software become commercially available.

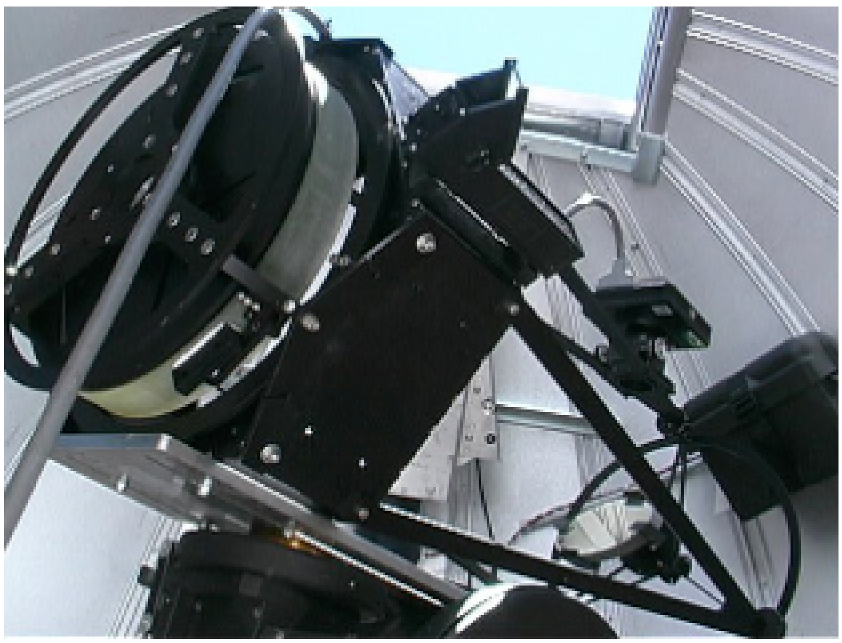


Figure 3-12. The Raven Telescope

Table 3-2. AMOS Telescope Optical Specifications

Element	Parameter	3.6-meter[14]	1.6-meter	1.2-meter - B29	1.2-meter - B37	BD/T	LBD
	Clear Aperture	363.0	157.0	121.9	116.8 [11]	80.0	60.96
	Focal Length	546.7	439.3	366.3	366.7	236.22	147.07
	f-number	1.5	2.80	3.00	3.14	2.95	2.41
Primary	Perforation	47.0	30.02	34.29	34.29	25.2	16.58
	Figure	Paraboloid	Paraboloid	Paraboloid	Paraboloid	Paraboloid	Paraboloid
	Wavefront Error[2]		λ / 20	λ / 7.6	λ / 19[11]	λ / 28	λ / 10[10]
	Reflectance[3] (%)	0.900	0.876	0.904	0.901	0.902	0.89 [10]
	Vertex Separation	515.6	360.6	309.2	294.7	190.5	122.2
	Clear Aperture[4]	25.32	28.70	19.93	23.82	15.8	11.0
	Focal Length	37.71	-95.5	-67.09	-88.29	-45.72	-24.71
	F-Number[5]	1.49	3.39	3.53	3.71	2.95	2.41
Secondary	Perforation	3.41	4.0	4.13	5.00	NONE	NONE
	Figure	Hyperboloid	Hyperboloid	Hyperboloid	Hyperboloid	Paraboloid	Paraboloid
	Wavefront Error		λ / 12	λ / 4.3[10]	λ / 4.3[10]	λ / 34	λ / 10[10]
	Reflectance (%)	0.980	0.859	0.855	0.868	0.90	0.9 [10]
	Clear Aperture[4]	38.16	15.56 x 22.00	N/A	6.00 x 22.23	15.6 x 22.1	10.3 x 10.7
Tertiary	Wavefront Error	λ / 20	λ / 21	N/A	λ / 21	λ / 63	λ / 10
	Reflectance (%)	0.98	0.898	N/A	0.904	0.49 [13]	0.90
	Wavefront Error	λ / 20	N/A	N/A	N/A	λ / 24	λ / 6.5
Fold Mirrors[1]	Reflectance (%)	0.98	N/A	N/A	N/A	0.96	0.95
	Number	4 through 7	N/A	N/A	N/A	5	3
	Clear Aperture	N/A	N/A	N/A	N/A	N/A	89.4
Pointing Flat	Wavefront Error	N/A	N/A	N/A	N/A	N/A	λ / 7.1
	Reflectance (%)	N/A	N/A	N/A	N/A	N/A	0.8 [10]
	Eff. Focal Length	72,601.32	2500	2459	1983	Afocal	Afocal
	f-number	200	15.9	20.2	17 [10]	N/A	N/A
	Magnification[6]	14.5	4.78	5.61	4.34	5.17	5.95
System	Half Field of View[7]	0.44 mrad	0.8 mrad	1.0 mrad	1.5 mrad	1.0 mrad	5.6 mrad
	Wavefront Error[8]	λ / 10	λ / 9.2	λ / 3.8	λ / 4.2[11]	λ / 16	λ / 3.7
	X Diffraction Limit		1.26	4.0	3.1	1.1	4.0+
	Throughput[9]		0.62	0.72	0.66	0.32	0.62

Note : All figures measured in centimeters unless noted otherwise.

1 Cumulative values for all fold mirrors which follow tertiary mirror	9 System throughput includes all reflections and obscuration losses @ 0.67
2 Wavefront error (OPD) is twice surface error and includes angle of incidence dependence. rms waves at HeNe 632.8 nm ; rms misfigure and random errors are rss'd	10 Engineering estimate ; measurement or specification not available.
3 Reflectance represents current measurement if available, or the following coatings and is not necessarily an accurate indication of the current mirror performance 0.99 = Denton FSS-99 0.98 = Gold 0.90 = Aluminum 0.88 = Aluminum with SiO overcoat 0.49 = Denton FSS-99 and 50% apodization	11 B37 primary is stopped to 116.8cm diameter.
4 Clear aperture is at full field.	12 LBD configured for HI-CLASS system with magnification of 5.95 - Magnification of 4.69 also available.
5 f-number is for on-axis beam.	13 Assumes apodized mask on tertiary for 50% transmission - throughput can be doubled by using max. R tertiary. This will eliminate use of BD/T Boresight Camera.
6 For afocal systems, magnification is the ratio of primary to secondary focal lengths or clear apertures. For focal systems, magnification is the ratio of the exiting chief ray and the half-field angles.	14 Alternate Secondary available with the following differences: Clear Aperture = 25.72cm Focal Length = 39.275 cm f-number = 1.52 Perforation = 3.05 System changes as a result of using alternate secondary are: Focal Length = 11,607.00 f-number = 32 Magnification = 13.97
7 Unvignetted field of view	
8 For system configuration using all mirrors listed	

Mount Control Systems

Harris Mount Control System (MCS)

The Mount Control Systems (MCS) software directs the operation of the 1.2-meter, 1.6-meter, and BD/T telescope mounts. The MCS allows each mount to independently acquire and track targets with a high degree of precision and to collect high quality positional and sensor data. In addition, this data may be interchanged between the 1.2-meter, 1.6-meter and BD/T mounts. The LBD mount currently operates independently. A separate mount operator traditionally supervises each mount.

The MCS software for each telescope, designated MCS1.2, MCS1.6, and MCSBD/T consists of several modules. The 1.2-meter, 1.6-meter and BD/T systems reside in separate Harris 500 computers to control its respective mount. The LBD MCS has been replaced with a version of the new Observatory Control System (OCS), based on the Motorola 68040 computer and VME I/O cards. All systems are similar in function, structure and organization, yet each module satisfies the unique mount-specific requirements. Each includes the Mount Model (MM) and calibration utility peculiar to its own telescope and the installed sensors.

Predicted target position is derived from the real-time solution of target equations of motion. These are based on Kepler's Laws and include higher order corrections. Auto-tracking of accelerating objects, such as firing second or third stages of sounding rockets, is also possible using TV-based image guiding.

Six tracking modes are provided:

- Ballistic mode for tracking orbital (such as artificial satellites) and sub-orbital targets (such as ballistic missiles).

- Sidereal mode for tracking stars.
- Ephemeris mode for tracking targets, such as the planets and asteroids whose trajectories can be defined accurately by ephemerides.
- Static mode for mount testing and evaluation.
- Accelerating mode for tracking thrusting stages of rockets.
- Radar slaving mode to allow positioning of the telescope to coordinates provided by the Kaena Point FPQ-14 radar.

OCS

AEOS and the existing MSSS telescopes will be linked under a site-wide command, control, communications and data system called the Observatory Control System or OCS. The OCS provides an efficient, reliable, and integrated architecture to facilitate control, communication and data management throughout the site and to~~e~~ the users. The modern computer and communication technologies employed are focused on the production of high density information products to fuse the imagery, metric, thermometric, and other site data that are available.

The fundamental building blocks for OCS are the telescope control systems, the communication system, the data management system, and the operations management system. The telescope control system consists of the mount control system, the gimbal controller, the integrated acquisition and tracking system, the sensor systems, and the peripheral telescope system control which includes thermal control, video control and dome control. The communication system is the hardware and software network that facilitates the transfer of control and data information within the site and to the outside world. The communication system is based on a client-server communication model and is the basic paradigm for remote operation and script language control of all assets. The data management system provides the data processing, management distribution, reporting and storage of MSSS data products. Examples of MSSS data types include: metric, image, radiometric, adaptive optics, control, meteorological, acquisition, and tracking, telescope parametric, operational, and maintenance data. The operations management system consists of the mission planning and scheduling of the MSSS assets.

OCS uses an extension of the MCS software used in the Harris Mount Control Computers. Some goals of the new Observatory Control System (OCS) include single operator control of other MSSS mounts, hand off from one mount to another, mission simulation for operator training and rehearsal, and tracking of powered accelerating vehicles.

Tracking Characteristics

The 1.6-meter Telescope

Tracking is done in the polar and declination axes with the azimuth axis set to a fixed position optimized for the track. All three axes are driven by torque motors and ride on hydraulic bearings. Mount position is derived from 23-bit shaft-angle encoders having a least significant bit equivalent to 0.15 arc seconds.

Stellar observations can be made at any azimuth but are normally performed with the azimuth axis set to align the polar axis to true north. The mount is then used as a classical astronomical mount, with the declination axis fixed and the polar axis rotating at the sidereal rate to perform the track.

Tracking of orbital and sub-orbital targets is usually performed with the azimuth angle set to point the polar axis 180 degrees from the azimuth at which the object culminates (culmination occurs at the highest elevation angle reached by the object on the pass). Most of the tracking motion then takes place about the polar axis with only small angular motions in the declination axis.

Mount capabilities include angular accelerations to 2 degrees/sec^2 and angular tracking velocities to 3 degrees/sec under ideal conditions (early acquisition, bright test object, away from sun or moon). Absolute pointing accuracy to within 2 arc seconds rms, and tracking accuracy to within 1 arc second rms can be achieved.

The 1.2-meter Telescope

Tracking is done in the polar and declination axes with the azimuth turntable set to a fixed position optimized for the track. All three axes are driven by torque motors and ride on hydraulic bearings. Mount position is derived from 23-bit shaft-angle encoders having a least significant bit equivalent to 0.15 arc seconds.

Stellar observations can be made at any azimuth but are normally performed with the azimuth axis set to align the polar axis to true north. The mount is then used as a classical astronomical mount, with the declination axis fixed and the polar axis rotating at the sidereal rate to perform the track.

Tracking of orbital and sub-orbital targets is usually performed with the azimuth angle set to point the polar axis 180 degrees from the azimuth at which the object culminates (culmination occurs at the highest elevation angle reached by the object on the pass). Most of the tracking motion then takes place about the polar axis with only small angular motions in the declination axis.

Mount capabilities include angular accelerations to 2 degrees/sec^2 and angular tracking velocities to 3 degrees/sec under ideal conditions (early acquisition, bright test object, away from sun or moon). Absolute pointing accuracy to within 2 arc seconds rms, and tracking accuracy to within 1 arc second rms can be achieved.

The BD/T Telescope

The BD/T mount is an altitude over altitude gimbal system that allows for easy tracking of objects that pass near zenith. Since the horizon is limited by dome obscuration to the east and west, the major axis is oriented east to west and the minor axis is oriented north to south. This orientation allows tracking down to 20 degrees from the horizon in the north and south and down to 30 degrees from the horizon in the east and west.

Mount capabilities include tracking velocities up to 3 degrees/sec under ideal conditions (early acquisition, bright test object, away from sun or moon) and angular accelerations up to 4 degrees/sec^2. Variations from the track are within 1 arc second rms.

The LBD Telescope

Tracking is accomplished in the azimuth and elevation axes by the lightweight, gimbaled tracking mirror. The LBD is capable of pointing across a range of 95^o in azimuth and from 15^o to 95^o in elevation without a repositioning of the azimuth table. It can project a beam within a pointing error of approximately 2 arc-seconds rms.

Mount Calibration

Mount Calibration is the process of determining a set of mount parameters that allows modeling of shaft angle encoder biases, mount and telescope axis misalignments, and gravity-induced flexure as a function of the instantaneous attitude of the telescope (Figure 3-13). This calibration process enables the conversion of encoder readings into precise metric measurements and provides a computerized boresighting of multiple sensors. The system allows independent calibration of up to six different sensors on each mount. The basic mount calibration process consists of commanding the mount to look at a star, stepping the star onto the sensor boresight fiducial mark, and pushing the MARK button. The real-time Kalman filter will immediately update the mount parameters. The operator-induced angular differential motions or "steps" are automatically zeroed and the improved pointing is apparent by the improved tracking of the star relative to the sensor boresight as seen by the operator on the monitor.

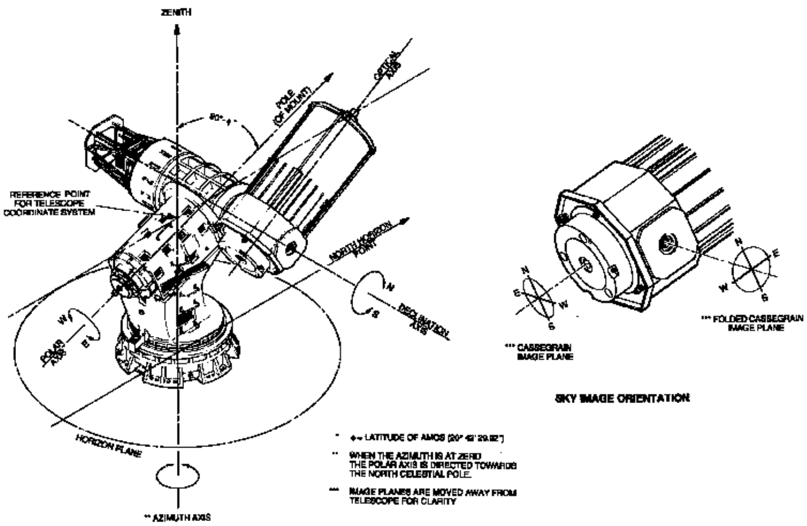


Figure 3-13. Telescope Coordinate System

A quantitative measure of pointing is displayed to the operator by current mean and rms residual pointing statistics.

Typically this process is repeated for ten or more stars representing expected angle position during operations. More than ten stars may be required if there has been a significant change in the mount or optical configuration since the previous calibration. Conversely, a three-star or even a one-star update may suffice if scheduling is constrained.

Pointing residual statistics are saved on the computer history tape and published as part of the Post Mission Events Log. Figure 3-14 is a sample of this sequence for the 1.2-meter B37 telescope.

4:29:53	DAY NO	13. WAS READ
4:29:57	STATIC	MODE SELECTED
4:29:58	SENSOR	2 SELECTED
4:30:13	SIDEREAL	MODE SELECTED
4:30:18	STAR ASN	397 RETRIEVED
4:30:52	MM 2 PT 1 MEAN(-3.2P, 5.2D) RMS(0.0P,0.0D)	
4:30:56	MM 2 PT 2 MEAN(-1.8P, 2.7D) RMS(1.4P,2.5D)	
4:31:34	STAR ASN	436 RETRIEVED
4:32: 2	MM 2 PT 3 MEAN(-1.5P, 2.6D) RMS(1.2P,2.0D)	
4:32: 8	MM 2 PT 4 MEAN(-0.8P, 1.7D) RMS(1.6P,2.5D)	
4:32:53	STAR ASN	8674 RETRIEVED
4:33:28	MM 2 PT 5 MEAN(-0.2P, 1.5D) RMS) 1.8P,2.1D)	
4:33:36	MM 2 PT 6 MEAN(0.1P, 1.1D) RMS(1.8P,2.1D)	
4:34:14	STAR ASN	8586 RETRIEVED
4:34:33	MM 2 PT 7 MEAN(-0.2P, 1.OD) RMS(1.8P,2.0D)	
4:34:40	MM 2 PT 8 MEAN(-0.3P, 0.8D) RMS(1.7P,1.9D)	

Figure 3-14. Sample Mount Calibration Sequence

Tracking

The AMOS mount control system software design features include multi-target equations of motion, real-time Kalman filter trajectory estimation, remote radar data links (FPQ-14 at Kaena

Point, Oahu and 4 MPS-25s at Barking Sands, Kauai), and precision angle and range measurements. Figure 3-15 illustrates the tracking sequence typical for each of the mounts.

During a mission, the Kalman filter may process metric data from both local and remote sensors. The Kalman filter uses a mathematical prediction process (in software) that takes into account data from other sources as well as mount operator inputs to optimize tracking by minimizing residual errors.

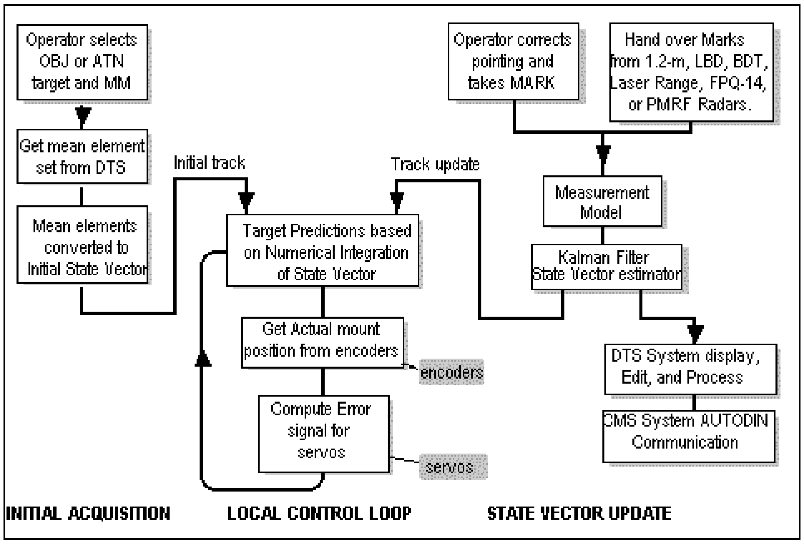


Figure 3-15. Real-Time Tracking Flow

The other sources of data used by the Kalman filter may include state vectors from the other mounts, radar data from the FPQ-14 on Oahu, or other radars observing the same object. Internal information is supplied by the mount model which is specific for each sensor on each mount. The mount model may be updated before the pass by making observations on stars along the expected path of the satellite or object pass. Periodic calibration updates are necessary because of mount changes with time, temperature, and changes in the sensor packages.

The difference between satellite tracking and ballistic test vehicle tracking is due to the difference in á priori knowledge. The satellite's true track, once it is up and orbiting without maneuvering, is highly predictable without operator intervention. The short flight of the ballistic test object, which only flies part of one orbit, does not allow for the refinement of measurement possible with the successive passes of the true orbiting satellite.

The predictive capability of the Kalman filter is especially important when tracking ballistic test vehicles from Vandenberg AFB. These follow elliptical Keplerian orbits about the center of the Earth, which intersect the surface of the Earth forming an interrupted orbit. The intended trajectory may be specified in advance, but the actual trajectory depends on many uncontrolled factors, minor variations in thrust due to aging of the solid fuel boosters, for example. The exact trajectory flown is set by controlling the period of thrusting or by maneuvering the third stage. Therefore the object that crosses AMOS' horizon is flying in an elliptical orbit whose exact elements were not known in advance. Nevertheless, some estimation of the state vector is needed to smoothly track the object. The object may be acquired by using the larger fields-of-view of the acquisition telescopes. The operator's act of pressing the MARK button, when manually introduced corrections seem to place the object on the boresight fiducial, updates the vector prediction to the best possible at that time. Typically, the object will again appear to drift off the boresight fiducial, and the operator will need to correct the track and press the MARK button again to update the Kalman filter prediction. The prediction controls the servo motors which move the telescope to track the object. Once really "on" and the residuals reduced to a minimum, range can be calculated from the instantaneous angle-angle data. This iterative process establishes the trajectory. A good track can be established more rapidly if the instantaneous range information is provided by some other means, such as a laser rangefinder.

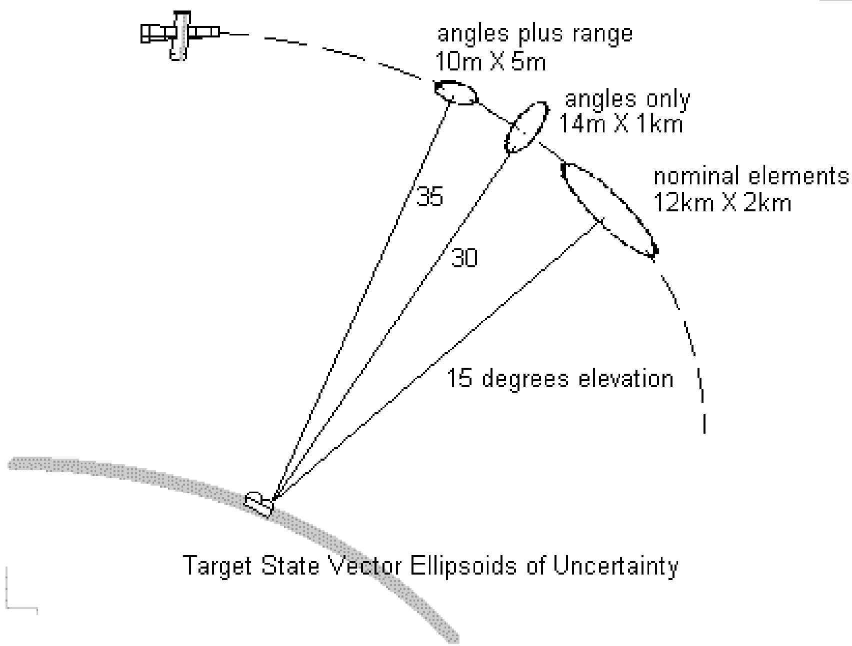


Figure 3-16. Tracking Uncertainties

The mount console operator has the option of enabling or disabling the updates from each sensor at any time. The operator also has the ability to select, at any time, which of six target state vectors will be used to command the mount.

Metric measurements, generated by a specific mount and sensor, will automatically update the target vector selected to command that mount. When the target is on bore-sight, the operator pushes the MARK button and the computer captures time-tagged readings of the shaft angle encoders.

Mount model corrections, computed as a function of the encoder readings and the selected sensor, are added to the readings to form a metric measurement. This metric measurement, along with its associated noise matrix, is then processed by the Kalman filter to provide an improved estimate of the selected target's state vector and covariance matrix. The measurement is also handed off to Figure 3-16 illustrates the reduction of the error ellipsoid surrounding the target object as the track is upgraded with time. Each "mark" tends to reduce the uncertainty and the Kalman filter performs the prediction of where the object will be shortly. The Kalman filter bases the prediction on the programmed knowledge that the object is obeying Kepler's laws in its progress about the Earth, the location of the MSSS relative to the center of the Earth, and the current calibrated mount model for the particular telescope and sensor in use. The ellipsoid is reduced in stages as the operator's bracketing process continues. The ellipsoid could be reduced more rapidly by using an accurate range measurement by radar or a laser rangefinder.

Target Acquisition

Initial conditions for tracking Earth-orbiting satellites are primarily derived from the on-line Space Surveillance Network catalog maintained by Space Command . The mean Keplerian elements are converted to osculating elements in the form of an inertial state vector suitable for real-time integration. Initial conditions for missiles are retrieved from database files and are updated in real-time by the liftoff time and an Inter-Range Vector (IRV) which may be supplied by an operator or Teletype message. Observatory communications are discussed in Section 5.

The computer initiates tracking at the predicted telescope motion time. If the target does not appear in the appropriate sensor field-of-view, acquisition is achieved by either searching about the nominal or utilizing data from a remote sensor that is already on target. The fundamental procedure is the handoff of the target from the acquisition sensor to intermediate field-of-view sensors until the target is on the desired boresight. This brings into play the multi-sensor modeling, use of remote sensors, and the rapid convergence of the real-time Kalman trajectory estimation process once the target is on boresight.

Systematic search patterns are available to facilitate acquisition of targets. Surveillance procedures are also available to examine a specified area of the celestial sphere through a cyclical step/stare sequence. These procedures can be defined, selected, and controlled by the operator. There are keys to enable, suspend, return to last step, advance to the next step, and to superimpose static or sidereal stare modes. There are also options to select the step size, stare period, and search pattern.

Sensors

Section 4 - SENSORS

The sensor systems at MSSS include imaging systems, infrared radiometers, visible light photometers and electro-optical acquisition and tracking systems. The recently added AEOS imaging systems include an active atmospheric turbulence compensating visible light imaging system, a high frame rate passive hybrid system utilizing a wavefront sensor for post-processing image enhancement, an adjustable aperture system that can be controlled to block turbulence phase shifts. and medium and long-wave infrared radiometric imagers. Metric information, elevation and azimuth angles, and calculated slant range are recorded by the Mount Control System (MCS).

The sensor systems are discussed in the following paragraphs arranged according to sensor function. Each section will contain a table for comparisons of all the sensors available on site.

Visible Imaging

Table 4-1. Visible Imaging Sensors

Telescope	Sensor	FOV, arc-sec	Sensor Element	Spectral Response	Rate
3.6-meter	AO/Vis	10, 24, 60	Si 512x512	700-1100 nm	>5 fps
1.6-meter	GEMINI Phase Diversity	6, 12, 24, 72	Si 128x128	400-900 nm	250 fps
1.6-meter	GEMINI Wavefront Deconvolution	6, 12, 24, 72	Si 128x128	400-900 nm	250 fps
1.2-meter	MAIS	60, 120, 240	CCD	400-1100 nm	30 fps

AEOS Adaptive Optics System

Introduction

The AEOS adaptive optics (AO) system is designed for compensated imaging of satellites in low Earth orbit. The adaptive optics system is used to mitigate the blurring effects of the Earth's atmosphere. The 3.6m telescope and AO system should produce the highest resolution images at AMOS. The normal operating mode for AO is in terminator conditions. Terminator runs from about one hour after sunset to one hour before sunrise when the site is in darkness but the satellite is illuminated by sunlight. A background subtraction capability is available in the AO system to accommodate operation one hour before sunset and one hour after sunrise. The highest resolution daytime images are taken by the GEMINI system (described later in this section) on the 1.6-meter telescope. These two systems provide complementary capabilities for AMOS. Raytheon Systems Company, formerly Hughes Danbury Optical System, was the prime contractor for the design and construction of the AEOS adaptive optic system.

The adaptive optics system consists of two control loops: 1) a tip-tilt control loop and 2) a higher order wavefront correction loop. The tip-tilt loop is used to correct for atmospheric image motion and tracking errors of the 3.6m telescope. The higher order loop corrects for all other optical aberrations.

At present, light from the target object is used to sense wavefront errors. The wave front sensor CCD uses light from 0.54-0.70 μm. The tracker CCD uses light from 0.450-0.50 μm. Wavelengths longer than 0.7μm are passed to the visible imager or to one of the seven coudé rooms. For targets brighter than visual magnitude 8, both loops can be operated simultaneously. For objects down to visual magnitude 12, higher order correction is not possible but the object provides enough signal for tracking. In the track only mode all radiation from 0.45-0.70 mm goes to the tracker CCD.   The next sections discuss features of each AO subsystem.

System Block Diagram

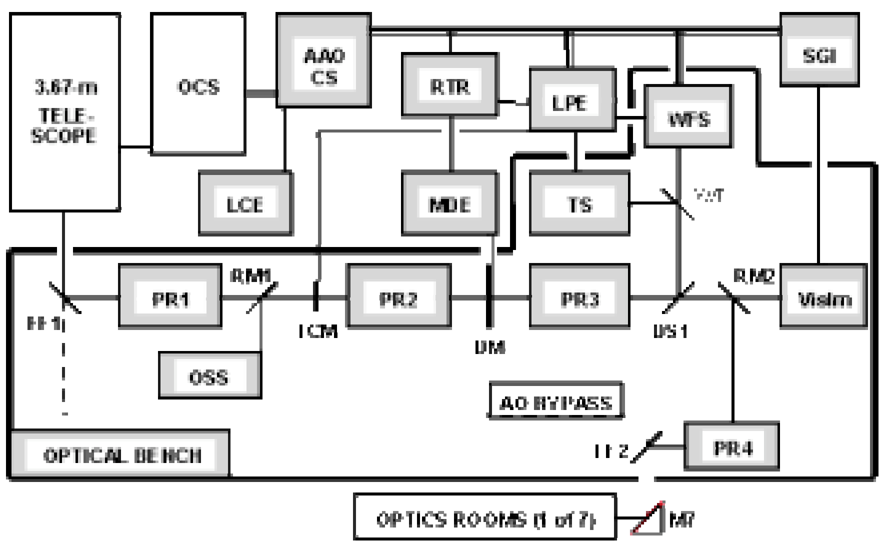


Figure 4-1. System Block Diagram

Figure 4-1 is a block diagram showing the major components of the system and interfaces to other elements of the AEOS facility. The light from the telescope is directed onto the optical bench by fold flat FF1, through the three pupil relays, PR1, PR2, and PR3, to the input pupils of the Tilt Sensor (TS), the Wavefront Sensor (WFS), and the Visible Imager (VisIm). The signals from the TS are processed by the Local Processing Electronics (LPE) to drive the Tilt Control Mirror (TCM). Signals from the WFS are processed by the LPE and Real-Time Reconstructor (RTR) to drive the Deformable Mirror (DM) via the Mirror Drive Electronics (MDE). The Optical Source Simulator (OSS) contains sources for alignment and calibration, which can be inserted by mirror RM1 into the path between PR1 and PR2.

Seven Optics/Experiment rooms are available for visiting experimenters. Beams can be switched to these rooms via the remotely controlled mirror M7. Experimenters have two choices for the type of beam they receive: (1) fold flats FF1 and FF2 can be rolled back to provide an uncompensated f/200 beam, with an angular magnification of 14.5 and a focus at a height of 1.17 m located in the Experiment Room 11.5 m from the inside wall of the coudé Room, (2) RM2 can be inserted in front of the VisIm, directing a compensated beam through pupil relay

PR4 to provide a 10-cm collimated beam, with the primary mirror re-imaged in the Optics Room 3, from the inside wall of the coudé Room.

The AEOS Adaptive Optics Control System (AAOCS) controls the adaptive optics subsystems and records quick-look data for testing and determining system performance. The Silicon Graphics Inc (SGI) computer controls, and records data from, the VisIm. The Local Control Electronics (LCE) contain the logic and controllers for actuating the electro-mechanical mechanisms in the system. The Observatory Control System (OCS) maintains executive control of the telescope, adaptive-optics system, and other sensors. Data recorded by the adaptive-optics system and Visible Imager are transferred to the OCS for processing and archiving.

Optics

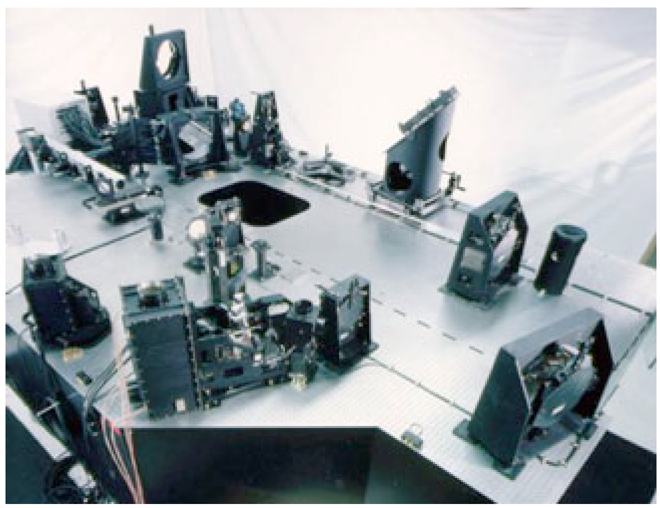


Figure 4-2. AO Optical Assembly

A photograph of the Optical Assembly is shown in Figure 4-2. The three pupil relays re-image the primary mirror of the telescope to the TCM, DM, and the input pupils of the TS, WFS, and VisIm. The beam diameters at the TCM, DM, and input pupils of the sensors are 4 cm, 27 cm, and 2 cm, respectively. The dichroic splitter (DS1) reflects wavelengths shorter than 0.7 μm to the TS and WFS and transmits longer wavelengths to the VisIm. The W/T selector has a dichroic splitter that reflects wavelengths shorter than 0.540 μm to the tracker and transmits longer wavelengths to the wavefront sensor. [When the system is used for tilt-only correction, the W/T selector has a mirror that reflects all radiation to the tracker.] The optical system is all-reflective, except for a BK7 window at the top of the AO room, and the two dichroic splitters. All mirrors are coated with a protected, enhanced silver coating, Denton FSS-99. The band-averaged transmissions from PR1 to the input pupils of the Tilt Sensor and Wavefront Sensor are 0.72 and 0.86, respectively, and the transmission at 750 nm to the Visible Imager is 0.83. The Optical Source Simulator (OSS) contains a broadband Xenon lamp and a diode laser, which can be switched into the optical path for alignment, calibration, and system checkout.

WFS

The wavefront sensor includes front-end optics, a 32 x 32 lenslet array, a 128 x 128 pixel CCD detector, and read-out electronics. The front-end optics include an input tilt mirror and a pair of Risley prisms for system alignment, a magnification group for re-imaging the input pupil on the lenslet array, and a moveable mirror for inserting an internal calibration source. The input tilt mirror, Risley prisms, and the focus of the magnification group can be remotely controlled to optimize the registration of the wavefront sensor and deformable mirror.

The MIT Lincoln Laboratory supplied CCD detector has 21-μm square pixels, a high quantum-efficiency (> 92% at 650 nm), high pixel-to-pixel uniformity, high transfer-efficiency (> 98.7%), and low read noise (< 9 electrons at a 2-MHz rate). Dark current is less than 2 nA/cm-2 at 23 ^{o}C. The device is cooled by a thermo-electric cooler, and normally operated at 0^{o}C.

The camera can be run at frame rates from 500 to 5000 Hz. There are 16 output ports. The analog output is digitized to 12-bits at a gain setting of 3.2 electrons per digital count. The camera can be run in a co-add mode, with 2 x 2 pixels binned as they are read out to give "quad" subapertures, allowing the camera to be operated at a 2520-Hz frame rate with the 2-MHz digitizer. A dark-current map is recorded before a run, stored in memory, and subtracted pixel-by-pixel as the device is read out.

Real-Time Reconstructor and Servo Control

Phase reconstruction is accomplished through a matrix multiply of the 32 x 32 x 2 slope vector at rates up to 2520 Hz. The subsystem is designed to provide 16 different reconstruction matrices and 16 different servo coefficient sets, which can be changed on command within one frame time. A modified least-squares reconstruction is currently implemented, with the matrix coefficients generated by performing an array of poke tests. This minimizes sensitivity to non-uniformity in subaperture gain and actuator stroke. Other features include full-aperture tilt removal on a frame-by-frame basis and focus offload to the secondary mirror of the telescope.

Deformable Mirror

The deformable mirror, manufactured by Xinetics Inc., has a 28.8-cm diameter, 2-mm thick ULE facesheet, supported by 941 lead magnesium niobate (PMN) actuators, spaced at 9 mm intervals on a square grid. The facesheet is coated with Denton FSS-99. The 810 control actuators operate over ± 30 volts around a 70-volt bias and produce a stroke of ± 2.4 μm. Each channel is fused for protection and has individual Zener diode protection to limit interactuator stroke to 2 μm.

Tilt Control Subsystem

The Tilt Sensor consists of a focusing lens and a 64 x 64 pixel silicon CCD detector. A f/4.7 or f/1.7 lens can be selected, giving fields-of-view (FOV) of 79 and 216 μrad, respectively. The CCD detector has 21-mm square pixels, a high quantum-efficiency (> 80% over the 500 to 700 nm band), high pixel-to-pixel uniformity, high charge transfer efficiency (> 99.99%), and low read noise (~ 13 electrons at a 2.5 or 4.22-MHz rate). Dark current is less than 4 nA/cm^2 at 25^{o}C. The device is cooled by a thermo-electric cooler, and normally operated at 10^{o}C.

The camera can be run at frame rates from 500 to 10,000 Hz, and has 4 output ports. The analog output is digitized to 12-bits at a gain setting of ~ 16 electrons per digital count. A selectable threshold is applied before calculating the centroid.

To achieve the maximum possible bandwidth for a given target size, the height of the track gate (in rows) is set to target size (number of rows with pixels above threshold) plus four rows. A burst read is made through the rows above and below the track gate. Only the pixel data within the track gate are digitized. For small targets only the pixel data in the two center ports are used for the centroid.

The Tilt Control Mirror faceplate is a 5.3-cm diameter Beryllium substrate, and is coated with Denton FSS-99. The mirror has a center flexure and is driven in push-pull by four linear voice-coil actuators. In the 4-cm beam, the mirror angular dynamic range is ± 10 mrad per axis and the cage-mode pointing stability is < 1.9 mrad, rms. These correspond to ± 220 µrad LOS range and < 42 nrad, rms, LOS pointing stability output space. The mirror is designed to minimize reaction torque to the optical bench.

The Tilt Control subsystem includes an automatic spiral scan acquisition mode, used for initial acquisition of the target if it is not seen within the sensor's FOV and for subsequent re-acquisition if track is broken.

Visible Imager

Figure 4-3 is a schematic of the Visible Imager. The camera is a Pentamax 512 x 512 pixel CCD cooled detector array. The maximum frame rate is slightly greater than 4 Hz. The spectral range is 0.7 to 1.1 mm. The field of view can be remotely selected, from a choice of 51, 120, or 300 µrad. The optical system includes two six-position spectral filter and neutral density (ND) filter wheels, a remotely controlled dove prism for derotation, and a dispersion corrector. An integrating sphere calibration source can be translated in front of the assembly for radiometric calibration of the camera.

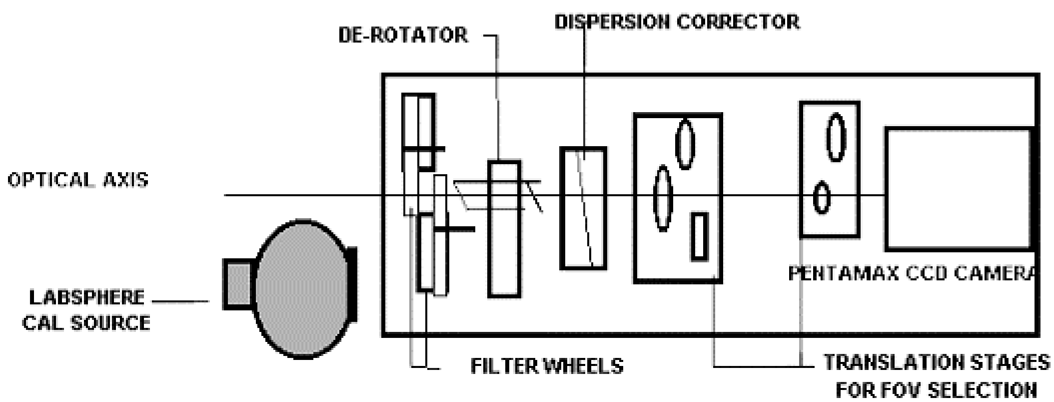


Figure 4-3. Vis-Imager Optical Schematic

MOTIF Advanced Imaging System (MAIS)

The Motif Advanced Imaging System (MAIS) is designed to provide metric and image data on targets in bright, daylight conditions. MAIS uses a Pulnix CCD Imager to produce a video image which is recorded on NTSC video tape or optical disk.

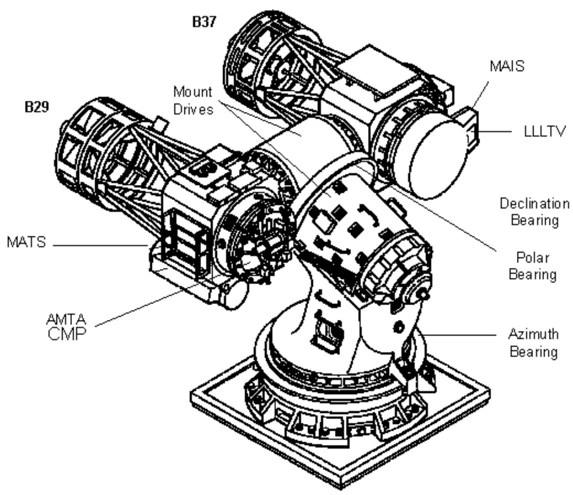


Figure 4-4. 1.2-meter Telescope Sensor Locations

Together with the LLLTV camera, MAIS is mounted on the rear Blanchard surface of the B37. When MAIS is operating, no other instrument can use the B37 beam. The system has three fields of view, 60 arc seconds, 120 arc seconds and 240 arc seconds. There are six spectral filter options plus neutral density filter options.

The main feature of the MAIS instrument is an adjustable aperture in the conjugate image plane of the telescope equivalent entrance aperture (approximately several meters ahead of the plane of the secondary mirror support spider). This permits adjusting the effective diameter of the telescope to within several r_o values to screen out unwanted phase distortions.

These apertures are actually in the portion of the beam that images the secondary telescope mirror and its support structure. The aperture stop wheel carries eleven specially shaped aperture plates and one wide-open position:

1) 0.892 in.
2) 0.814
3) 0.735
4) 0.656
5) 0.577
6) 0.499
7) 0.420
8) 0.341 (off axis)
9) 0.262 (off axis)
10) 0.184 (off axis)
11) 0.105 (off axis)
12) Open

For positions (8) through (11), off axis means the aperture is completely to one side of the central obscuration in the primary mirror.

There are six spectral filter options;

1) WG280 Clear
2) OG530 Yellow
3) OG550 Orange
4) OG570 Deep Orange
5) RG610 Red
6) Open

There are places for six Neutral Density (ND) filters, (not installed at this time). Other specifications are:

- FOV: 60, 120, 240 arc seconds.(to the CCD diagonal)
- Spectral response: 350 to 1100 nm.
- Output: 3/4-inch videotape, NTSC format.
- Data Rate: 30 frames per second

The camera is a Pulnix TM-745 CCD array and is outfitted with an electronically selectable range of effective "shutter" speeds from 1/60 second to 1/10,000 second in eight steps.

GEMINI

The GEMINI system is designed for satellite imaging and consists of four focal plane arrays. It collects, processes, and analyzes imagery data in the LWIR, MWIR, and visible wavelengths.

The GEMINI system records and processes atmospheric turbulence-degraded images of satellites and astronomical objects under dark or daytime sky conditions. The system is deployed on the 1.6 m side blanchard enclosure.

The Visible sensor operates in a 600 - 900 nm band, and is capable of recording images at up to 250 frames per second. A second focal plane array can be used for either wavefront sensing or phase-diversity. Additionally, GEMINI provides a near real-time post-processing capability. The primary processing algorithm for GEMINI visible Focal Plane Arrays (FPAs) for near-real time and general post-processing is based on the Bispectrum image reconstruction technique.

GEMINI also includes a two band infrared (IR) imaging and acquisition system, operating at 3 - 5 and 9 - 14 μm.

Main Computer / Console

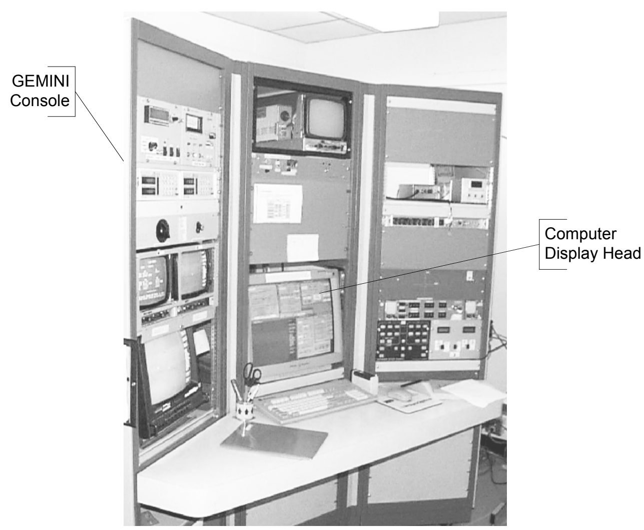


Figure 4-5. GEMINI Operator Console

Figure 4-5 shows the console for the GEMINI system with the display head of the main computer located in the center. All sensor control, image acquisition, recording, display, and communications functions are performed by a SGI ONYX computer system. Initial configuration includes four 250 MHz. R4400 CPUs (expandable to 36), 512 MB RAM (expandable to 2 GB), a 3-D graphics processor capable of generating both high-resolution images with 12 bits of intensity (color) and NTSC composite video. Data storage devices include a 4GB disk for operating system and software, a CDROM, an 8MM tape drive with hardware compression, and 12 2GB disks for image recording and storage. These devices are distributed over five fast wide SCSI busses for maximum performance. An ATM and two Ethernet channels are connected to the OCS data communications switch for transmitting images to and from MHPCC and OCS interfaces.

Optics Package

Figure 4-6 shows that the GEMINI optics package is mounted in a side-blanchard instrument enclosure which houses the two dual focal-plane optical systems, and a four position beamsplitter which is used to direct all the light from the telescope to either package, or to split the light between the two optical systems through the use of a dichroic spectral filter.

The High-resolution imaging package consists of two MIT Lincoln Laboratory 128x128 pixel silicon (Si) focal plane arrays (FPAs) and optics to form images on one or both cameras.

The IR imaging package consists of two Amber Engineering Inc. 128x128 pixel FPAs and associated optics housed within a cryogenically cooled vacuum dewar. The MW detector material is InSb and the LW material is Si:Ga.

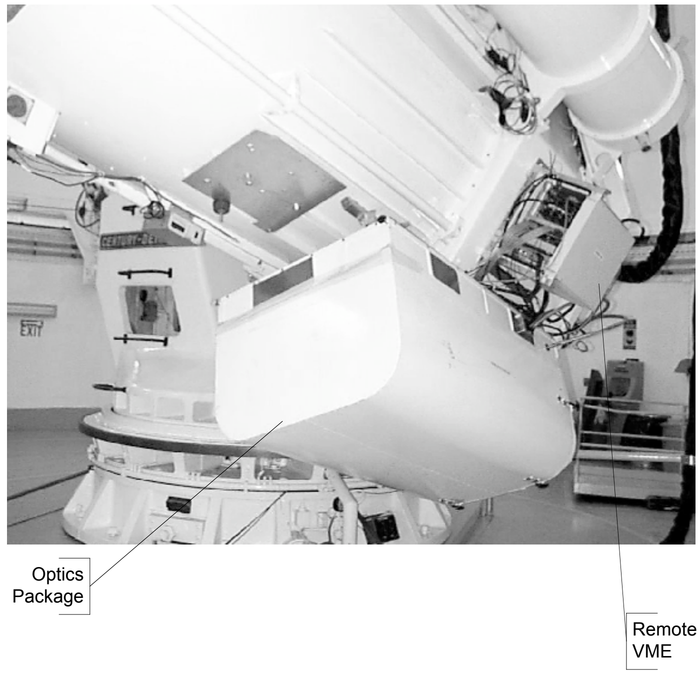


Figure 4-6. GEMINI Optics Package

Figure 4-7 shows that light from the tertiary mirror passes through the side blanchard beam port and arrives at the four position Input BeamSplitter (IBS) which can be positioned to transmit all light to the IR dewar window, reflect all light to the high-resolution imager (Visible Sensor), or split the light spectrally by transmitting wavelengths longer than 2 um and reflecting shorter wavelengths . The combination of the visible and IR imaging systems allows GEMINI to be operated in four distinct modes: Speckle, Phase Diversity (PD), WaveFront Sensor (WFS), and IR. These four modes are further described in the following paragraphs.

Visible Optics Path

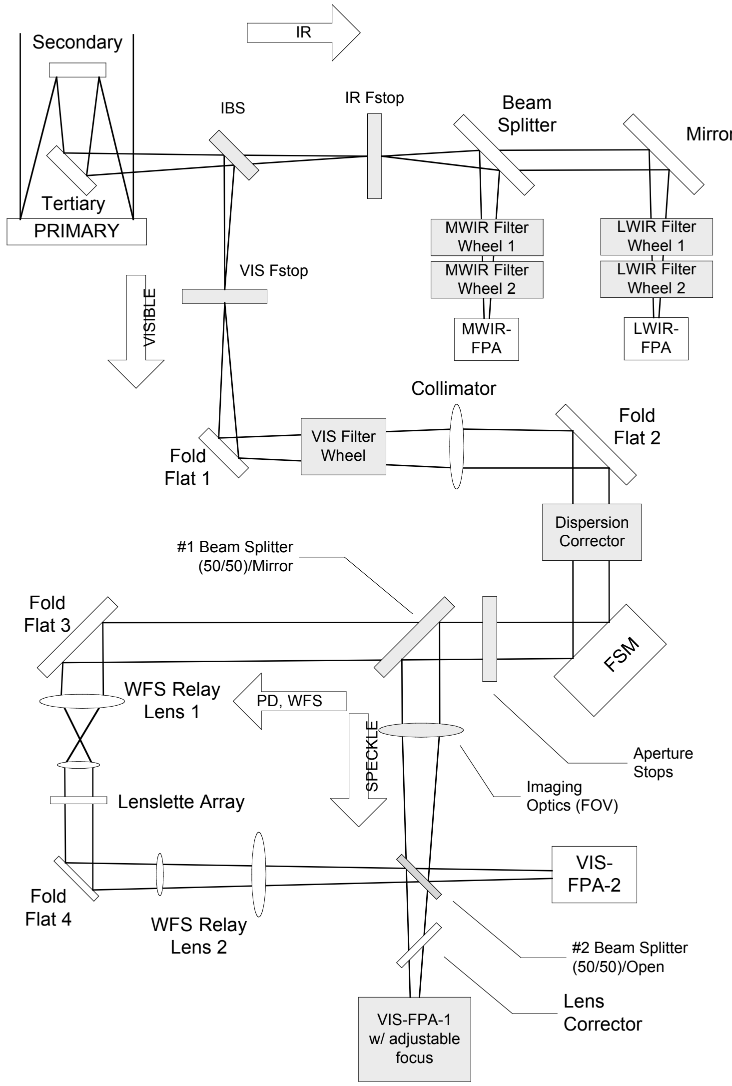


Figure 4-7. GEMINI Optical Schematic

Light entering the visible sensor first encounters the six position Field-stop. Only the 72" circular stop setting will allow the beam to pass. The other Field-stop positions contain self-illuminated calibration sources.

A flat mirror then turns the incoming light beam through a 12-filter filter wheel, a 30 cm focal length lens, two dispersion corrector prisms, the fast steering mirror (FSM), the four position aperture stop, and the two position beamsplitter, BS1. In WFS mode an amplitude beamsplitter transmits 50% of the light to the WFS optics, and reflects 50% to the imaging lens turret. The transmitted beam from BS1 passes through a lens, which relays an image of the primary mirror to a lenslet array that acts as a Hartmann wavefront sensor. A second lens relays the 200+ images formed by the lenslets to VIS-FPA-2. The light transmitted by BSI goes to VIS-FPA-1. In Speckle and Phase Diversity modes all light is reflected to the lens turret by BSI. In PD mode an amplitude beamsplitter (BS2) directs half the light to each MIT/LL FPA, while in Speckle mode all light is transmitted to VIS-FPA-1 (Speckle). The transmitted beam from BS1 passes through a lens, which relays an image of the primary mirror to a lenslet array that acts as a Hartmann wavefront sensor. A second lens relays the 200+ images formed by the lenslets to VIS-FPA-2

Speckle Mode

In Speckle mode, a single camera is used to provide short exposure imagery. Bispectrum wavefront reconstruction may be performed in near real-time using a dedicated MHPCC IBM SP2 computer connected via an ATM data link. Post-processing of complete data sets can be performed using the SP2 or, at a reduced rate, using a Silicon Graphics, Inc. (SGI) Onyx computer on site. Other reconstruction algorithms such as Multiframe Blind Deconvolution are being investigated

Phase Diversity Mode

In the Phase Diversity mode, two visible cameras, with coincident fields of view, are used to collect simultaneous short exposure images with a known defocus added to the second image. The images are to be provided to a high-speed digital computer for post processing.

Image data is collected from the two 128 x 128 Lincoln Laboratory's Focal Plane Arrays (FPA) and stored in real-time to a local disk subsystem. Both cameras run at frame rates of 10 to 250 Hz corresponding to approximate exposure times of 100 to 4 ms. As in the Speckle mode, four Fields of View (FOVs) (6.2, 12.4, 24.8, 74.3 arcsec) (30, 60, 120 and 360 μm) are provided, and a tracker driving the FSM is used to keep the target in the center of the field of view.

Wavefront Sensing Mode

In Wavefront Sensing mode, a lenslet array is utilized in conjunction with the second camera to form a Hartmann wavefront sensor that provides a direct measurement of local wavefront tilt for each subaperture of the telescope pupil. As with the Phase Diversity mode, in the wavefront sensor mode, two visible cameras are used to collect simultaneous short exposure images. Instead of introducing defocus in the second path, however, the appropriate optics are placed in front of the second camera to produce Hartmann images. The two sets of images are combined using the deconvolution from wavefront sensing (DWFS) technique to produce the processed images. The DWFS processing will be used on an experimental basis on the SGI Onyx computer and/or at the MHPCC.

Infrared Mode

This capability is implemented through the use of the long wave (LW) and mid-wave (MW) infrared FPAs located within the cryogenic dewar mounted on the side blanchard. An additional set of camera electronics, with modified FPLA logic, is used to interface these FPAs with the GEMINI computer. A dewar Control Electronics circuit board is used to control the tandem spectral filter wheels for each channel and the common two position field-stop. Figure 4-8 diagrams the beam path while operating in IR mode. Light entering the Zinc-Selenide window passes through the field-stop located immediately inside. The field-stop has two positions: OPEN which provides a square FOV 1 mrad X 1 mrad (206" X 206"), and SLIT which is used in conjunction with the prisms mounted in the filter wheels.

Infrared Imaging

Table 4-2. Infrared Imaging Sensors

Telescope	Sensor	FOV, (arc-sec)	Sensor Element	Spectral Response(μm)	Rate (fps)
3.6-meter	LWIR	29	Si:As 240x320	8.3 - 9.2 10.1 - 12.9	60
1.6-meter	GEMINI IR	206 square	Si:Ga 128x128 InSb 128x128	9 - 14 3 - 5	10-125

GEMINI IR Capability

The capabilities of the Enhanced Longwave Spectrometer/Imager, or ELSI, have been integrated into the GEMINI sensor system on the side blanchard of the 1.6-meter telescope system. The IR portion of the sensor consists of dual infrared acquisition/imaging arrays, which provide simultaneous coverage of the MWIR 3 – 5 μm and LWIR 9 - 14 spectral bands. Both bands employ a square array (128 X 128) providing a field of view of approximately 1 milliradian by 1 milliradian. The LWIR band uses a gallium doped silicon (Si:Ga) array. The MWIR band uses an indium antimonide (InSb) array. The detector elements are each 50 μm X 50 μm. The GEMINI IR wide field of view allows simultaneous imaging of multiple reentry vehicles and other test objects. The GEMINI IR optical arrangement is shown in Figure 4-8.

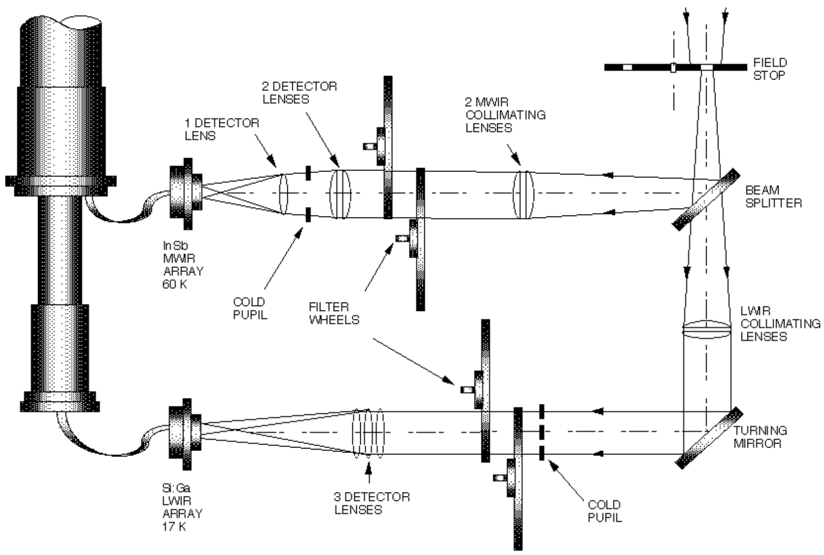


Figure 4-8. GEMINI IR Optical Schematic

Two indexed wheels on each array optical channel carry a variety of bandpass filters and a prism for a dispersive mode as well. Characteristics of the GEMINI IR arrays and the filters are shown in Figure 4-9.

The tertiary mirror of the telescope is not only a beam directing switch (switching between a straight through and a folded configuration), but can serve as a "nodder", shifting the optical axis back and forth so the IR arrays look at the object with the sky and then at the sky without the object. This is necessary because radiation from the atmosphere, i.e., the sky, is many times brighter than typical objects. To enhance the contrast, one set of data is subtracted from the other; the difference is due to the target image.

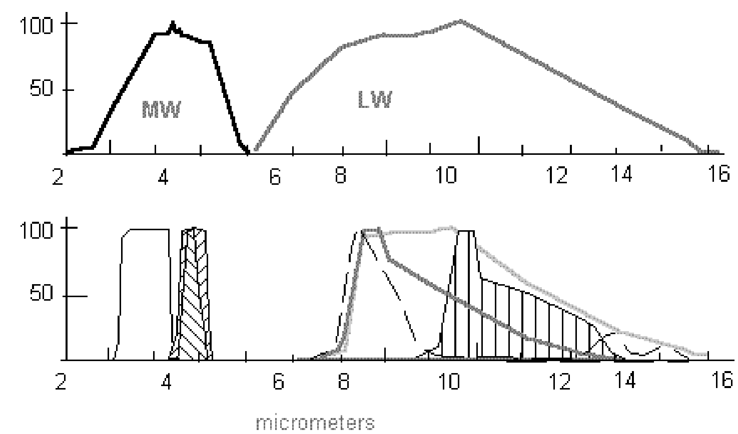


Figure 4-9. GEMINI IR Spectral Characteristics

The MWIR array operates at 60 degrees Kelvin and the LWIR array operates at 17 degrees Kelvin. The FPA rate is variable, from 10-125 frames per second, digitally recorded with 12-bit resolution. RS-170 videotapes are also available simultaneously.

In the LWIR, the NEI (Noise Equivalent Irradiance) at the telescope entrance aperture is typically > 3×10^{-16} watts/square centimeter for the LWIR array measured over a band width of 8 – 12 μm. In the MWIR, the NEI is 2×10^{-17} watts/square centimeter measured through a narrow-band filter from 4.5 - 5.0 μm (June 1993). The results of sensitivity measurements tend to vary from time-to-time, depending on many factors including an azimuth dependency on EMI from the nearby television and FAA transmitters. The NEI figures must be regarded as order of magnitude.

AEOS LWIR Imager

The AEOS LWIR Imager is a dual-Focal Plane Array (FPA) sensor that provides both background-limited sensitivity and near diffraction-limited imaging performance in the 4 - 5 μm and 8 -13 μm regions. Both FPAs simultaneously image the same object. These images can be combined and used to produce a thermal map of resolved objects.

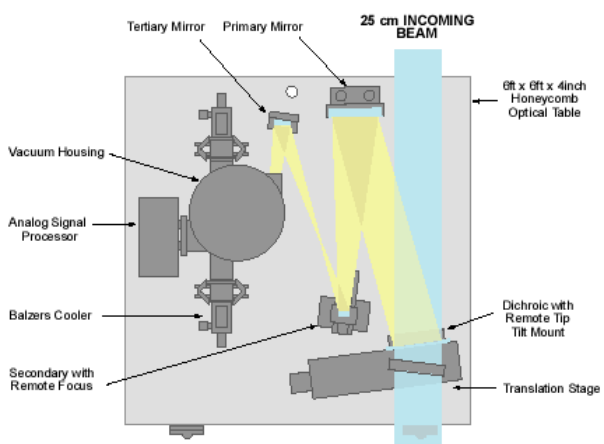


Figure 4-10. AEOS LWIR Optical Schematic

The sensor optical assembly attaches to the yoke tine of the AEOS telescope gimbal, while the control electronics mount to the side of the telescope. A schematic of the optical assembly is shown in Figure 4-10; a photograph of the system mounted on the telescope is shown in Figure 4-11. The sensor's data processing system is remotely located in the AEOS Control Room. As mentioned above, the optical assembly is mounted on the side of the telescope, between mirrors four (M4) and five (M5) of the coudé optical path. A removable dichroic beamsplitter located along the coudé path between M4 and M5 intercepts the f/200 beam and reflects thermal IR energy into the LWIR Imager. The dichroic transmits visible and near-IR energy to the coudé rooms. From there it can either be sent to one of the experiment rooms, or to the AEOS Adaptive Optics system. This permits simultaneous collection of visible and LWIR image data. The dichroic has a built in compensator plate that ensures the alignment of downstream optics is not affected by the insertion of the dichroic. The transmission of visible light is greater than 85%.

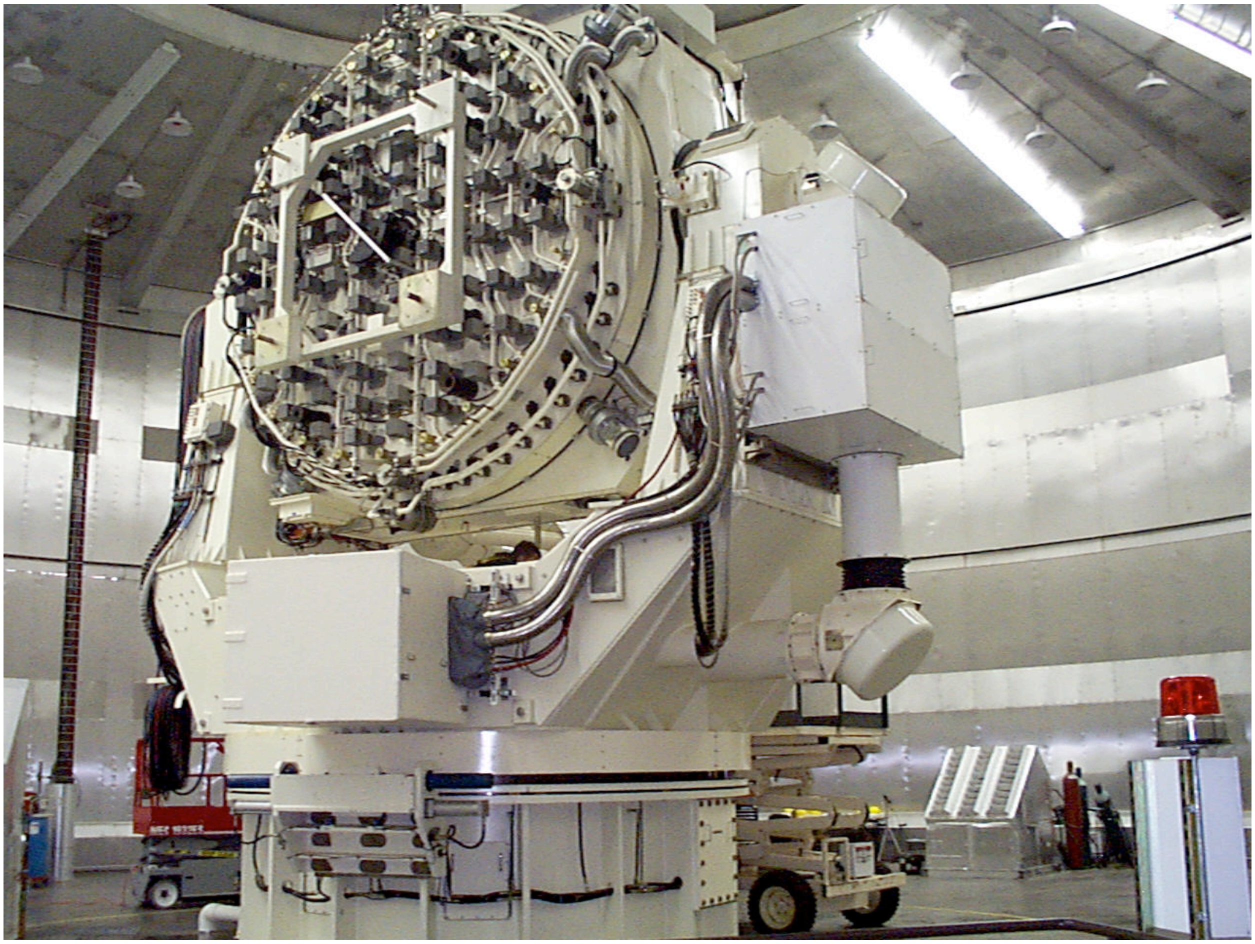


Figure 4-11. LWIR Imager Mounted on AEOS Telescope

This photograph shows the LWIR Imager mounted on the AEOS telescope. The box mounted on the side of the telescope contains the optics; the box mounted on the back of the telescope contains the control electronics. The metal tubes running between the two boxes contain coolant lines and control cables.

The AEOS LWIR Imager beam is re-imaged by a warm Three Mirror Anastigmat (TMA) off-axis telescope. The TMA output is directed into a cryogenically cooled, vacuum enclosure containing spectrally selective optics, calibration sources, and the two FPAs.

The principal spectral region in which the AEOS LWIR Imager collects data is the astronomical N-band (8-13 μm). This region affords the highest SNRs over the 200-350 Kelvin temperature range exhibited by most artificial satellites. The sensor's two FPAs are identical 240x320 element blocked impurity band (BIB) Si:As arrays, of which only a 200x200 subset of pixels is used. This provides a total field of view of 143.6 μradians x 134.8 μradians (29.6 arc-seconds x 27.8 arc-seconds). The difference in dimensions is caused by an anamorphic distortion in the optics.

The full astronomical N band is divided by a dichroic beamsplitter centered on the 9.6 μm ozone absorption band. Blocking filters are used with each FPA to limit their long-wavelength responses and thereby minimize the extraneous background flux at the detectors. Each FPA has a dedicated filter wheel that holds up to six spectral filters for selection of specific measurement sub-bands. The filter wheel position may be changed in less than 0.5 seconds to permit rapid multi-spectral sampling. The currently available filters are listed in Table 4-3.

Table 4-3. Filter Characteristics for Each Focal Plane Assembly

Filter Position	FPA1	FPA2
1	Pupil Imaging Lens	Dark Block
2	Dark Block	10.1-12.9 µm
3	8.35-9.19 µm	10.1-12.9 µm + ND1
4	8.35-9.19 µm + ND1	Spare
5	8.35-9.19 µm + ND2	11.1-12.2 µm + µm ND1
6	8.35-9.19 µm + ND3	11.1-12.2 µm + µm ND2
7	Spare	12.7-13.5 µm
8	Spare	12.7-13.5 µm
9	Spare	Spare

Table 4-4. Operating Modes for Each Focal Plane Assembly

Mode Position	FPA1	FPA2
1	High Gain 13ms	High Gain 7ms
2	High Gain 9ms	High Gain 5ms
3	High Gain 6ms	Low Gain 11ms
4	Low Gain 12ms	Low Gain 8ms
5	Low Gain 7ms	Low Gain 4ms
6	Low Gain 3ms	Low Gain 2ms
7	Configurable	Configurable

The AEOS LWIR Imager can take data with any combination of the filters listed in Table 4-3, and he modes listed in Table 4-4. The FPAs are read out 60 frames per second, but only 10 of those frames can be saved due to the access speed of the hard drive. The exact data storage rate can be set from 0.1-10 HZ.

The AEOS LWIR Imager achieves background-limited performance over the entire range of background levels likely to be encountered during nighttime operations. The temperature of the warm optics in the telescope and LWIR Imager is typically around 0-5°C. Atmospheric thermal emission contributes to the total background and becomes significant at larger zenith angles. For near-zenith viewing through a cold, dry atmosphere (i.e., low background condition), the NEFD, referenced to the AEOS telescope aperture, is approximately 1 x 10^{-17} W/cm^2 or lower, depending upon the specific spectral bandpass. This NEFD is for a single frame collected with a 10 ms integration time.

The AEOS LWIR Imager is normally operated from the AEOS Control room from a dedicated workstation. The AEOS LWIR Imager operator controls the sensor and can select the data rate and method. As mentioned above, the data rate can be varied from 0.1-10 Hz. The system can be instructed to store a set number of frames (1-250), or data acquisition can be turned on and off at the operator's discretion. The system can co-add frames to improve the signal-to-noise-ratio. The operator also chooses the filters and modes used. If the conditions change, these choices can be changed in the midst of a data collection. Once the data collection run is complete, the data are reduced using the standard data reduction scheme. There are a few minor choices to make, such as whether temperature maps, radiance images, or both are to be computed; everything else is automatic. It takes several seconds for each image to be processed. The system is fully compatible with the Observatory Control System, and can be controlled from OCS scripts.

Data Reduction

The system has two internal black bodies that are used for calibration. These sources are used to perform non-uniformity correction (NUC) to high precision (< 0.1%), monitor offset drift, and quantify the absolute radiance responsivity of each pixel. During operations, a mirrored chopper wheel rotates and allows the FPAs to look at one of the black bodies once per second. This establishes an offset reference file for each second of the data collection. Any drifts in the FPA are removed when these files are compared with a baseline file established during the responsivity calibration.

The raw signal at each pixel is the sum of the target brightness and the background radiance. The latter includes both atmospheric radiance and the self-emission of the uncooled sensor/telescope optics. For each pixel, a third-order calibration polynomial is used to convert the raw signal into an equivalent calibration source radiance. The true target radiance is then found by subtracting the background radiance and dividing out the transmission factors of the optics and atmosphere.

The background to be subtracted is estimated within each frame of data. A rectangular annulus, or "picture frame" is drawn around the target, but far enough away to exclude significant target energy. The size of the picture frame adapts to the target image. The pixels contained within the picture frame are averaged to define the per-pixel background level that is subtracted from the entire image.

The image is then divided by the estimated transmissions of the warm optics and atmosphere. This yields the final target-centered radiance map. Target intensity (watts/steradian) of near-Earth objects is also reported for each frame of data, as follows. The radiance signals of all pixels enclosed within the background frame are summed and the result is multiplied by the solid angle instantaneous field of view and by the squared range-to-target.

Temperature maps are computed via a two-filter band-ratio algorithm. Radiance images from both FPAs are co-aligned and then divided. The resulting band-ratio value at each pixel is converted into an apparent gray body temperature via a third-order polynomial function.

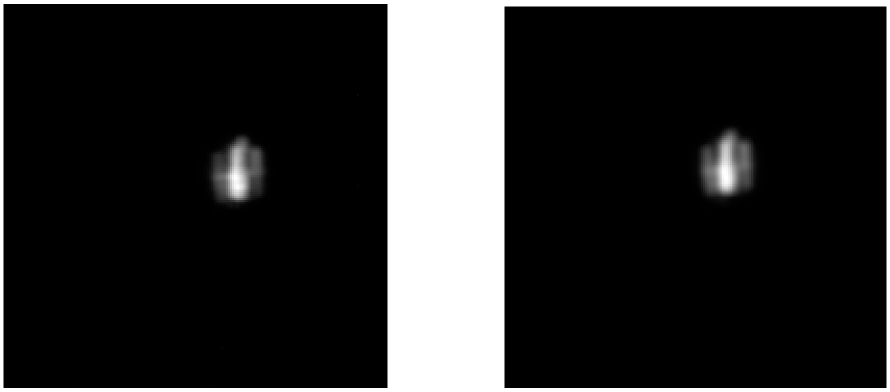


Figure 4-12. Hubble Space Telescope

This shows two images of the Hubble Space Telescope taken simultaneously with the AEOS Longwave Infrared Imager. The left image is from FPA1 from 8.35 – 9.13 µm and the right is from FPA2 in the 11.1 – 12.2 µm. The images were processed with the standard data reduction algorithm.

Radiometry/Photometry

Radiometry photometry is a measurement of luminous flux density or irradiance of light within a given waveband over time. MSSS provides several sensor systems on the 1.2-meter and AEOS mounts (Table 4-5) dedicated to photometric and radiometric measurements from the visible to the infrared spectrum. These sensors include the AEOS Radiometer System (ARS), the Contrast Mode Photometer (CMP), and the Advanced Multicolor Tracker for AMOS (AMTA). Time-resolved radiometric and photometric measurements are valuable for the understanding of Earth-orbiting satellites, missiles, and astronomical objects.

Table 4-5. Radiometric / Photometric Sensors

Telescope	Sensor	FOV, (arc-sec)	Sensor Element	Spectral Response (µm)	Rate (fps)	Data Format
3.6-meter	ARS	51	Si:As 128x128	17-23	200	Digital
		51	Si:As 128x128	8-14	200	Digital
		38	InSb 256x256	2.0-5.5	60	Digital
		51	Si: 128x128	0.4-1.0	500	Digital
1.2-meter	AMTA	50 square	Si:As 32 discrete	8-13	50	Digital
1.2-meter	CMP	9, 18, 36, 60	PMT	.300-.920	50	Digital

AEOS Radiometer System

The AEOS Radiometer System (ARS) is a four channel imaging system designed to provide radiometric data from the visible to the very long wave region of the spectrum.

The ARS is permanently mounted in a Nasmyth port on a corner of the trunnion of the 3.6m telescope. The ARS can be used simply by redirecting the primary beam to the port using the telescope's tertiary mirror. The mounted ARS optics and electronics package is shown in Figure 4-13 below.

Figure 4-13. ARS Mount Position

AEOS Radiometer Optical Configuration

The ARS contains an initial flat mirror (M1) that immediately folds the broadband radiation from the

telescope target into the ARS optical bench, directing the beam onto a second spherically powered mirror (M2). The M2 mirror directs the beam into an initial image plane. The M1 and M2 mirrors are super-polished and nickel-plated with a FSS-99 substrate. This coating is the same material used to coat the three AEOS telescope mirrors. The ARS optical configuration is shown in Figure 4-14.

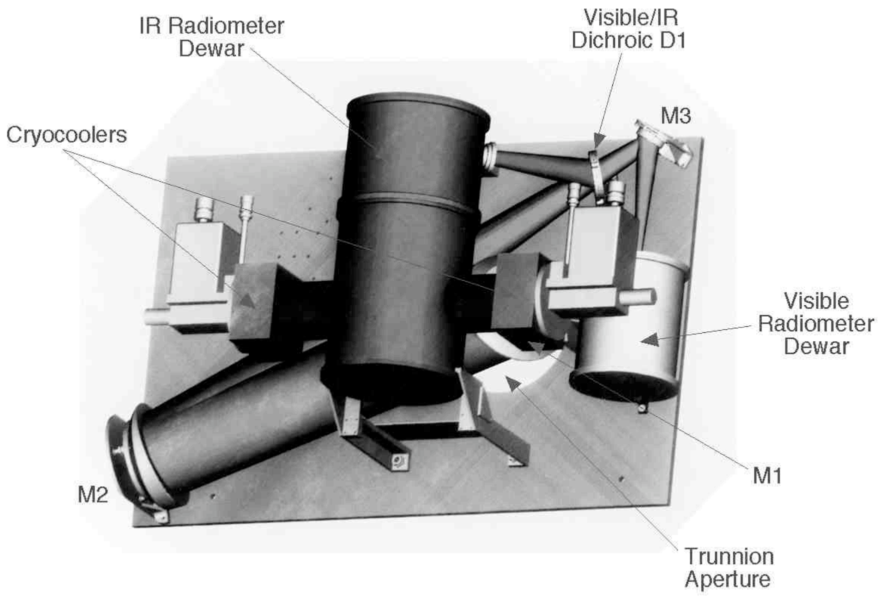


Figure 4-14. ARS optical bench with the telescope beam path indicated.

Prior to the focus of M2, the first of three ARS dichroics splits the visible radiation from the infrared in order to direct the subbands into their proper channels. Visible radiation passes through D1 and its wavefront tilt compensator, D1 complement, which then reflects off a third fold mirror into the visible sensor channel. All radiation longer than approximately 2 μm reflects off the front surface of D1 and is directed into the cryogenic IR dewar that houses the three infrared sensor channels.

AEOS Radiometer Visible Energy Channel

The visible target signature radiation passes off the ARS M3 and immediately through two high speed filter wheels that control the irradiance level as well as the spectral sub-band. The visible beam then arrives on the 500 Hz visible CCD focal plane array. The filter wheels are capable of changing optical density or spectrum within one second. Spectral bands include the visible B, V, R, I, and full 0.39 – 1.06 μm bands. The spectral responsivity chart is shown in Figure 4-15. The visible relay optics that image the target onto the CCD are of a Matsukov reflective/refractive design. On good seeing nights, the measured image quality from the AEOS telescope aperture through the ARS optics on the visible channel in the V band is on the order of 3 μradians FWHM within the 256 x 256 μradian field of view.

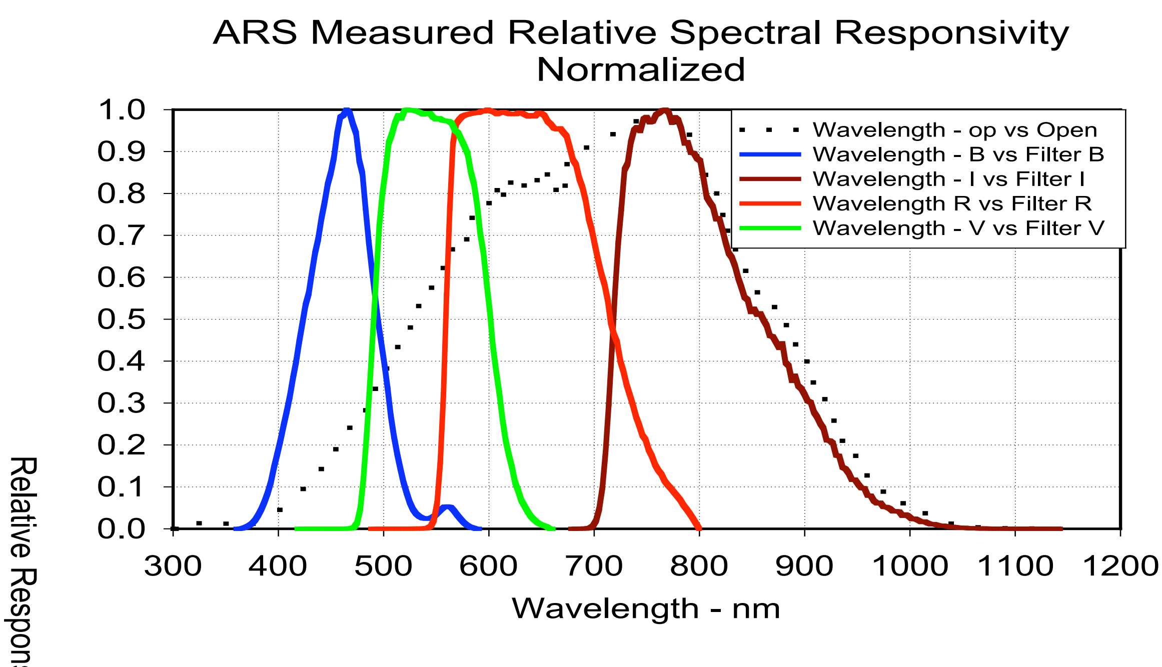


Figure 4-15. Visible Channel Spectral Response

AEOS Radiometer Infrared Energy Channels

Infrared target light reflected off the front surface of ARS D1 passes through a broadband coated KRS-5 window into a cryogenic dewar housing the fully independent MWIR, LWIR, and VLWIR channels. All reflective and refractive optics within the dewar operate at 60 degrees Kelvin to reduce optical backgrounds and control stray light within the IR channels. Two cryogenic dichroics, D2 and D3, are responsible for splitting the 2-5 μm, 7.9-13 μm, and 17-23 μm bands into the three channels. Each channel has a refractive relay system that brings the target image onto its FPA. High-speed cryogenic filter wheels provide both optical density as well as spectral sub-band control of light incident on each channel's FPA. The MWIR astronomical InSb FPA sees a 196 μrad field of view and collects imagery at 80 Hz. The LWIR channel coverage begins at 7.9μm and extends to 13μm, Figure 4-17, while the VLWIR channel covers from 17.5 to 19 μm, Figure 4-18. Both the LWIR and VLWIR channels use Si:As Focal Plane Arrays to collect imagery at 200Hz from a 256 x 256 μrad FOV. This custom dewar cryogenic design carefully balances thermal masses and conduction with heat loads to allow Si:As FPA operation at 10K, InSb operation at 45K, and optics temperatures at 60 degrees Kelvin. Cryogenic cooling is provided by a synchronous closed cycle helium system.

The MWIR band response is shown in the chart in Figure 4-16.

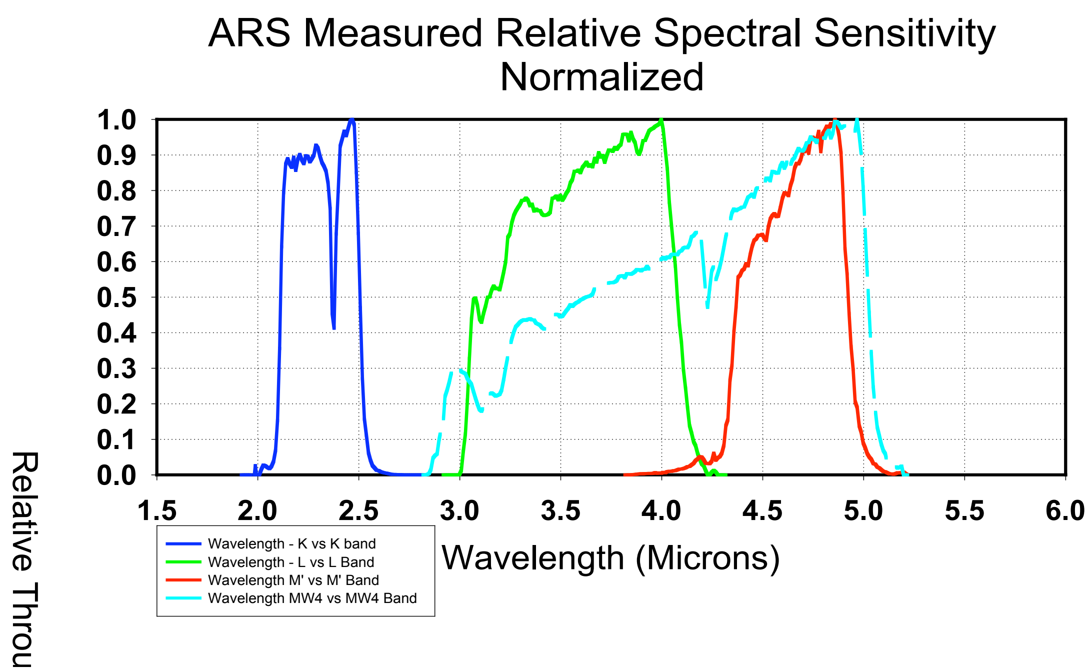


Figure 4-16. MWIR Channel Spectral Response

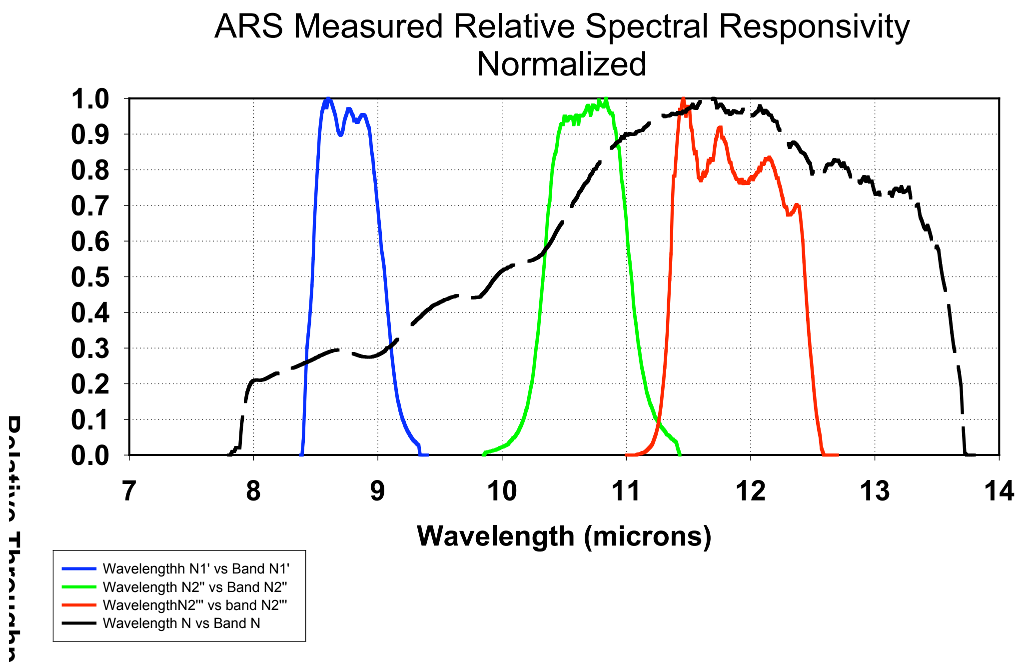


Figure 4-17. Channel Spectral Response

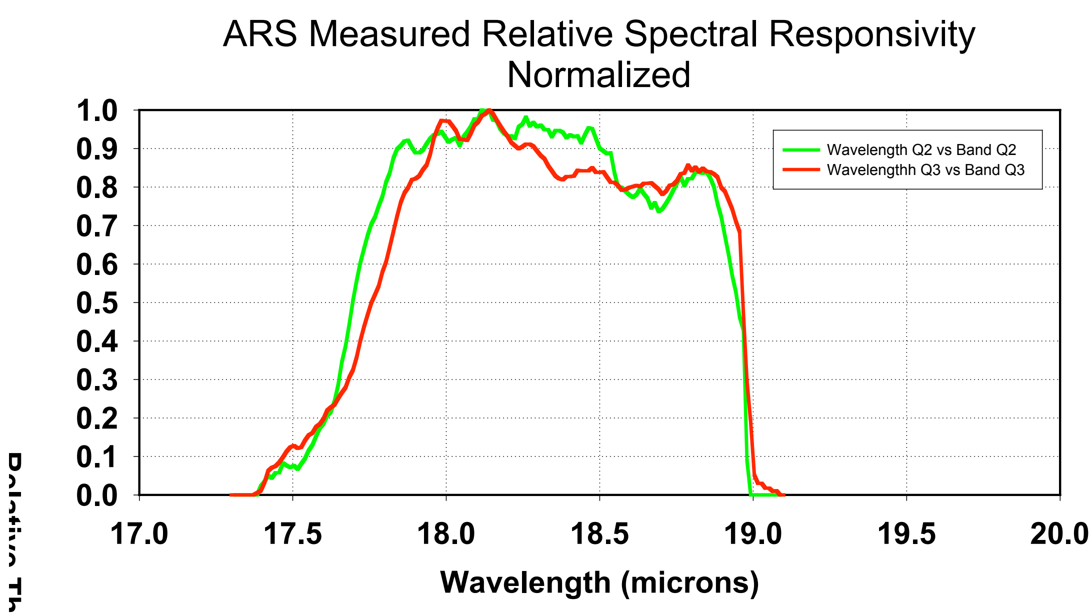


Figure 4-18. VLWIR Channel Spectral Response

AEOS Radiometer Sensitivity

These data are based on stellar observations using the ARS in a standard mode. Reference stars were selected from the IRTF bright standard star catalog. The IRTF listed brightness was used and corrected for ARS spectral bandwidth.

The ARS has several modes of operation. The data presented here are for the nominal fast frame mode, which includes the 20-frame average.

Band	Frame Rate (Hz)	Frame Averages	Effective integration time (sec)
Visible	500	20	0.040
MWIR	80	20	0.250
LWIR	200	20	0.100
VLWIR	200	20	0.100

ARS detection and tracking (SNR=100) of a 13.6 M_v star using an effective integration time of 5 sec. in the V band has been performed.

The atmosphere was included via a MODTRAN model for a typical day. A two-parameter model was constructed and fitted to the zenith angle.

The Noise Equivalent Flux Density (NEFD) is defined at the entrance of the AEOS aperture. This value includes the effects of the approximate 5.5% area obscuration due to the secondary, tertiary, and spiders. It does not include atmospheric effects from the aperture to space. The center band and the bandwidth are determined by the method of moments. The NEFD is an in-band number – it does not need to be modified for spectral bandwidth for these data.

	Band	Center Wavelength (μm)	□□	Effective integration time (sec)	NEFD (W/cm^2)
Visible	V	0.535	.09	0.040	3E-16
MWIR	L	3.62	1.01	0.250	9E-17
LWIR	N2”	10.69	.88	0.100	8E-18

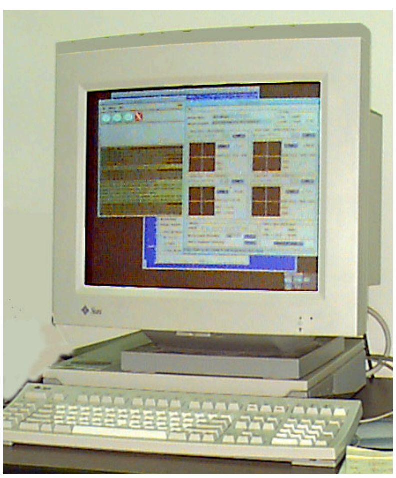
The noise floors are calculated for real-time standard deviations calculated on the data. There is a component of uncompensated spatial non-uniformity in the NEFD calculation.

AEOS Radiometer Data Processing

FPA Image data from all 3 channels is transferred in real time to a VME based host that is responsible for data reduction and radiometric post processing. The basic mode of operation is a traditional total energy mode where the target is placed in a window and the background is automatically subtracted leaving only the energy in the target. Reduced data products include:

- Time stamp
- Spectral band
- Window size
- Average background level
- Spatial standard deviation
- Total energy above background in window
- Reported track error

A customer control application and GUI allow the operator to both control the ARS and perform post processing data reduction from a single user's console. In addition the ARS is interfaced to the Observatory Control System allowing the telescope operator to confirm target acquisition, alignment, and closed loop tracking, Figure 4-19.



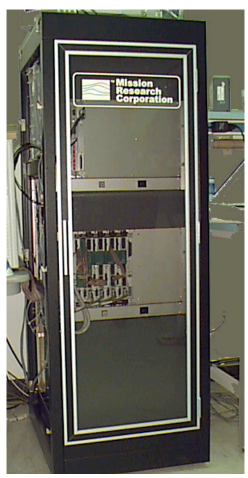


Figure 4-19. Sensor Diagnostic Computer (left) and Processor Subsystem (right)

Contrast Mode Photometer (CMP)

The Contrast Mode Photometer (CMP) shares the 1.2-meter B29 telescope light beam with the AMTA LWIR sensor. This provides the capability for simultaneous infrared radiometric (AMTA) and visible photometric (CMP) data collection. The nodding secondary on the telescope provides contrast mode operation; photons count up (+) when on the object and sky together and down (-) when on the sky alone.

The CMP sensor uses two uncooled, magnetically focused EMI 9658A (S-20R) photomultiplier tubes (PMTs). The two PMT channels can be operated individually. The sensor has color filters, neutral density filters, and field-of-view options, all remotely selectable from the control console.

Normally, to maximize the pass-band and improve the signal-to-noise ratio, the color filters are not used when observing satellites. The spectral characteristic without filters is the same as that of the sun. Against a dark sky, the CMP can detect 13th Magnitude objects. The filters may be used for atmospheric extinction determination with photometric stellar sources.

Two narrow spectral filters at 0.6943 μm and 0.498 μm wavelength, a clear (no filter) position, and the conventional astronomical UBVR filter system (when combined with the spectral response of the PMTs) are provided. This allows accurate measurements of the observed objects calibrated by astronomical "standard" stars. The effective UBVR filter wavelengths (nominal) are:

- U 0.350 μm Ultraviolet
- B 0.430 μm Blue
- V 0.550 μm Visual yellow
- R 0.680 μm Red.
- The neutral density filters are:
  0, 0.3, 0.6, 1.0, 2.0, 3.0, and opaque or
  100%, 50%, 25%, 10%, 1%, 0.1%, and 0% transmission.

Because of its large dynamic range, 10^8 or twenty stellar magnitudes without using the neutral density filters), the CMP is particularly useful for glint measurements of objects illuminated by the sun. Much can be learned about the unknown object by studying the CMP glint data together with the simultaneously recorded infrared signature. For example, if the object carries a flat germanium infrared window (germanium reflects visible light), it may reflect a brilliant pulse of sunlight. The normal to the window bisects the angle between the sun and the observatory as seen from the object. The detection of a glint of this kind indicates the probability of a visible-light reflective window on the object.

Uniform repetition of glints might indicate rotation of the object that probably means it has gone unstable or that it is spin-stabilized. The field-of-view is adjusted not in the usual sense, by changing the effective focal length but by inserting defining apertures over the photo cathode. Available fields-of-view are: 9, 18, 36, and 60 arc seconds.

The apertures do not affect the intensity of the signal provided the image lies completely within the aperture. A beamsplitter provides several options for splitting the visual beam between the boresight TV and the CMP.

Advanced Multicolor Tracker for AMOS (AMTA)

This infrared radiometer is an array of 32 Si:As Impurity Band Conduction (IBC) detectors, cryogenically cooled and capable of determining infrared spectral signatures after data processing. The detectors are made of groups of much smaller elements (100 μm by 100 μm) ganged together to form the pattern shown in Figure 4-21. Filters are divided among the 32 detector areas. The filter numbers, bandwidth, assigned detectors, and operational status are shown in Table 4-6.

Table 4-6. AMTA Detector Configuration

Filter #	Band (µm)	Detector #	Operational
0	Clear	01-08	No
1	3.1 - 4.2	11, 12, 13, 14	No
2	4.5 - 5.1	21, 22, 23, 24	No
3	8.1 - 9.2	31, 32	Yes
4	10 - 13	41,42	Yes
5	8.0 - 13	51 through 58,59,60	Yes
7	17 - 19	71,72	No

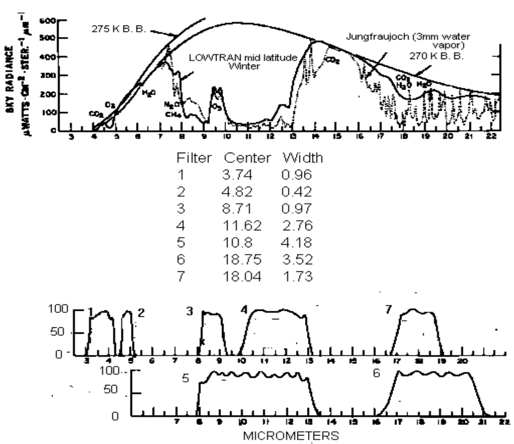


Figure 4-20. AMTA Spectral Bands

The actual transmission curves are shown in Figure 4-20. The first digit of each detector number indicates the filter superimposed on it. The electronics for several AMTA detectors has not been implemented as indicated by the operational status in Table 4-6.

In operation, the secondary mirror of the B29 telescope, driven by actuators, bends the optical axis of the telescope to accomplish (1) background subtraction, (2) quadrant tracking, and (3) spectral selectivity by choosing the sets of detectors having the spectral filters of interest. Two detectors can be sampled simultaneously, each at a rate of 50 Hz.

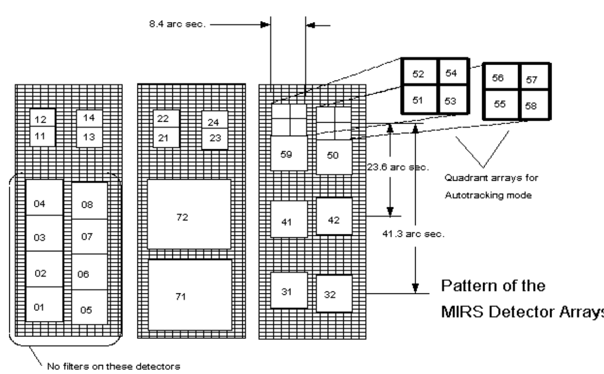


Figure 4-21. AMTA Detector Arrays

Metrics

Table 4-7. Metrics Sensors

Telescope	Sensor	FOV, (arc-sec)	Sensor Element	Spectral Response	Rate	Data Format
1.2-meter	LLLTV	260	ISIT	400-800 nm	30 fps	Video
1.2-meter	B29 Boresight	145	ISIT	400-800 nm	30 fps	Video
BD/T	BD/T Boresight	225	ISIT	400-800 nm	30 fps	Video

Low Light Level TV (LLLTV)

The Low Light Level Television (LLLTV) can be used in two ways. For relatively close, resolved targets, the LLLTV can provide both imaging data and metric (angle and time) data. It is also used to detect very faint (17^{th} magnitude) unresolved deep-space objects, providing metric data only.

The television camera in this package is used as the operator's primary boresight reference for metric measurements. The LLLTV package contains a Scanco SC-25 25mm Intensified SIT (ISIT) TV camera system, which is a high-gain, astronomical-quality camera capable of providing useful television pictures of very faint objects. This camera operates at photon-shot noise-limited levels of illumination and uses low-noise video signal processing electronics. The parameters of the LLLTV sensor are:

Table 4-8. LLLTV Specifications

FOV	4.4 arc-minutes
Resolution	1.0 arc-second at f/16
Color Filters	Unfiltered, orange, red, filter 3
Attenuation	0.00, 3.75, 7.90, 10.00 magnitudes
Camera Spectral Response	S-20R (400 to 800 nm)
Data Rate	30 fps
System Sensitivity	+17 visual magnitude (Dark Sky)
Output	3/4-inch tape, NTSC format

B29 Boresight TV

The B29 Boresight TV uses a Cohu ISIT camera equipped with a boresight reticle projector. The AMTA and CMP fields are aligned to the Boresight TV reticle that allows the Main Console Operator to maintain the target in the AMTA and CMP fields by keeping the object visible in the Boresight TV reticle. Note that the AMTA sensor itself can be used by an operator to track weak infrared targets.

BD/T Boresight TV

The BD/T Boresight TV uses an RCA ISIT camera equipped with a boresight reticle projector. The sensor resides at the focal plane of a reimaging system located inside the BD/T primary perforation. The BD/T Boresight can be used as a laser track sensor only if the beamsplitter tertiary is installed.

Raven

A Pentium class PC running Windows NT and TheSky controls the Raven telescope. TheSky is a commercial off the shelf (COTS) software package written by Software Bisque. TheSky package consists of several inter-communicating modules including:

- TheSky - application providing telescope monitoring
- CCDSoft - providing CCD camera control
- GPStfp - providing the interface to the Datum GPS receiver for accurate timing of the opening and closing of the CCD shutter
- TPoint - providing telescope mount modeling for accurate pointing
- Orchestrate - enabling scripting of telescope pointing, satellite tracking, asteroid tracking, camera acquisition, and data transfer
- Observatory - providing the capability to control the system over the Internet

The Raven telescope system also consists of a data processing workstation, a Silicon Graphics Octane UNIX running IRIX 6.4. Image files are analyzed to detect all stars in the field as well as any satellites present. The detected stars are matched against the nominal positions of catalog stars from the Hubble Guide Star Catalog. Using this computed transformation, the pixel positions of any detected satellites at shutter open and close are converted to equatorial coordinates. Annual (stellar) aberration is applied to the satellite's coordinate to account for light time travel variations due to the Earth's motion around the Sun. The corrected coordinates are then converted to B3 format and correlated against an online database of deep space satellite element sets. After correlation, the tagged metric observations along with magnitude estimates are saved to a data file.

Acquisition Telescopes

Table 4-9. Acquisition Sensors

Telescope	Sensor	FOV, arc-min	Sensor Element	Spectral Response	Rate	Data Format
3.6-meter	LFAT	162	ICCD	400-900 nm	30 fps	Video
3.6-meter	LAAT	7.5 / 3	ICCD	400-900 nm	30 fps	Video
1.6-meter	AATS	180, 30, 6	ISIT	400-900 nm	30 fps	Video
1.2-meter	MATS	180, 30, 6	ISIT	400-900 nm	30 fps	Video
BD/T	BATS	72	ISIT	400-900 nm	30 fps	Video
LBD	LATS		ISIT	400-900 nm	30 fps	Video

Large-Aperture and Large Field Acquisition Telescopes (LAAT/LFAT)

The 3.6-meter telescope has two acquisition telescopes. The Large Field Acquisition Telescope (LFAT) is for wide field acquisition, and the Large Aperture Acquisition Telescope (LAAT) is for narrow fields. The two acquisition telescopes both employ intensified CCD cameras, and provide multiple FOVs. Full FOV for the LFAT is 1.2 degrees, while that of the LAAT is selectable at 0.45 or 0.125 degrees. The acquisition sensors in the telescopes have a dynamic range which allows detection, display without image blooming, and tracking of targets with visual magnitudes ranging from at least +16 to as bright as -2

MOTIF and AMOS Acquisition Telescope Systems (MATS/AATS)

The MOTIF Acquisition Telescope System, (MATS) is mounted on the 1.2-meter B29 telescope, and the AMOS Acquisition Telescope System (AATS) is mounted on the 1.6-meter telescope. The acquisition telescope systems are used as finder telescopes for the primary optical systems by providing a visual reference by means of CRT monitors, for tracking stars and other targets within one of the three fields of view (3 degree, 30 arc-min and 6 arc-min). The seldom-used 6 arc-min field of view is not as bright, due to the slower f/ number. Fields of view can be changed as the target is centered in each to provide progressively more precise tracking.

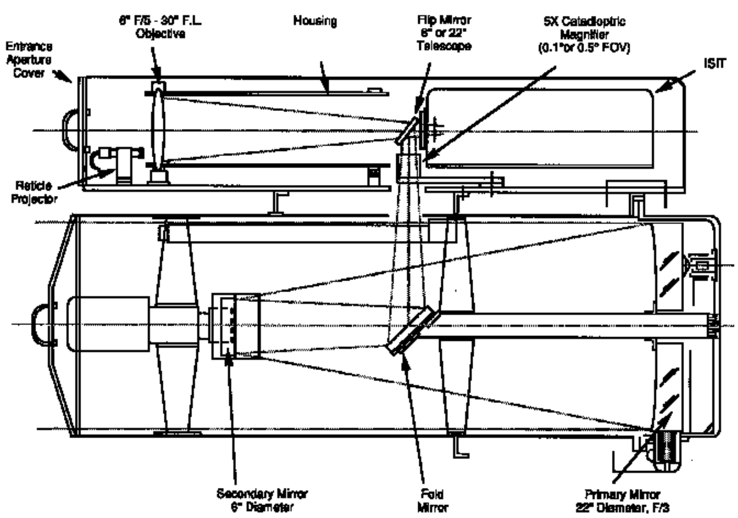


Figure 4-22. MATS/AATS Optical Layout

Within each system, two optical trains provide the three fields of view which are fed to a common 40mm diameter coherent fiber optic reducer in the ISIT television sensor. Both of these systems are based on identical 0.56-meter (22-inch) Ritchey-Chrètien telescopes, which provide the 0.5-degree field-of-view. Inserting a catadioptic converter increases the image size and reduces the field-of-view to 6 arc-min, but at the expense of the f/ number. The 3 degree field is provided by a 0.15 meter lens in the MATS, shown in Figure 4-22, and by a 0.20 meter (8 inch) catadioptic system in the AATS. The AATS also provides a choice of four spectral filters (Melles-Griot #, passes wavelengths longer than):

- 03FCG047 GG375 0.375 μm
- 03FCG107 RG665 0.665 μm
- 03FCG111 RG715 0.715 μm
- 03FCG780 RG780 0.780 μm

Each filter has a near-uniform step function transmission. Both systems contain intensity adjustable projection reticles.

In the 30 arc-min field for which the system was optimized, the telescope/television sensor system was designed to be capable of detecting 17th magnitude objects against a dark sky and 15th magnitude against a moonlit sky.

BD/T Acquisition Telescope System (BATS)

The BD/T Acquisition Telescope System (BATS) which provides a 1.2 degree diagonal field-of-view television finder for the BD/T. The objective is an f/5 lens of 0.15 meter diameter. The camera is an ISIT. The BATS is mounted on the telescope frame and does not share any of the optics of the BD/T.

LBD Acquisition Telescope System (LATS)

The Laser Beam Director is equipped with a flip-in optical adapter that allows the full aperture of the primary to be used as an acquisition telescope. The LBD Acquisition Telescope System (LATS) acquisition function is not capable of simultaneous operation with functions originating in the sub-dome room.

Laser Tracking

Table 4-10. Laser Tracking Sensors

Telescope	Sensor	FOV, arc-sec	Sensor Element	Spectral Response	Rate	Data Format
BD/T	LBS	*currently under design*				
LBD	VLT	90	ISIT	400-900 nm	30 fps	Video

Visible Light Table (VLT)

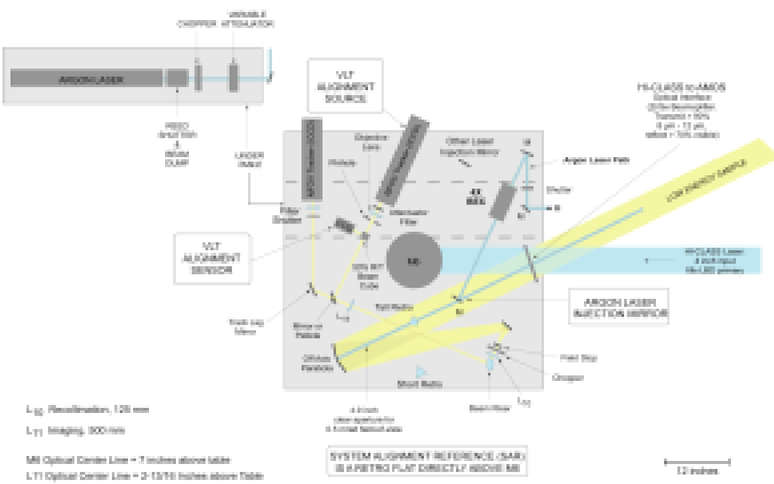


Figure 4-23. VLT Optical Schematic

Directly below the LBD (Figure 3-10) is the Visible Light Table (VLT) which contains the narrow FOV visible tracking ICCD that can see up to 10th magnitude objects. A HeNe laser and CCD in the VLT are alignment systems for HI-CLASS and LBD and can be seen in the VLT schematic in Figure 4-23. These VLT functions are also available for other visiting experiments using the LBD. Using time phased chopper wheels, the VLT/LBD can project a 2 W co-boresighted Argon Ion laser for LBD track of LEO retro satellites in shadow. A track lag mirror in the VLT compensates for LBD point ahead so that the laser illuminated target remains on the tracking camera center fiducial.

Section 5 - SUPPORT SYSTEMS

Astronomical Support

Although the primary mission at MSSS is the measurement of earth-orbiting satellites for Air Force Space Command, the accessibility and capability of its systems on Haleakala and Kihei provide a unique opportunity to support the astronomical community. As an example, MSSS has played an important role in the discovery and follow-up observation of asteroids. Two of these asteroid tracking systems are the Jet Propulsion Laboratory Charged-Coupled Device (JPLCCD) and the Near-Earth Asteroid Tracking (NEAT), both in collaboration with JPL. The systems have provided thousands of measurements of new and previously discovered asteroids to the Minor Planet Center (MPC) at the Smithsonian Astrophysical Observatory.

Sky Charts

Sky charts can be generated with the UNIX program Xephem, which is currently running on the OCS Control console. Xephem allows the user to display the sky at any epoch. Displayable objects include stars, planets, NGC objects, Messier objects, radio sources etc. User supplied lists of objects can also be displayed. In addition to Xephem, the MSSS library has the SAO Catalog and both the north and south volumes of the Uranometria.

Sky Surveys

MSSS does not have any sky surveys on site, but it does have Internet access that allows access to online surveys such as Digital Sky Survey and SkyView.

IR Calibration Stars

Precise infrared radiometric measurements can only be accomplished by calibrating with a catalog of accurate IR calibration stars. For visible photometry, there has long existed a series of well-known calibration star catalogs in the common astronomical U, B, V, R, and I wavebands, such as the Landolt star catalog. However, for the IR spectrum, only recent efforts to combine comprehensive ground-based measurements coupled with space-based sensors and more thorough atmospheric extinction models have resulted in IR calibration star catalogs of sufficient size and accuracy. In particular, the catalog of continuous stellar IR spectra developed by Dr. Martin Cohen and Dr. Mike Egan provides spectra irradiance values in units of watts/cm^2/μm of 422 stars from 1.22 to 35 microns with a 0.05 micron resolution and at an approximate accuracy of 2%. By convolving the transmission curve of each sensor and filter pair with the catalogued continuous stellar IR spectra, an IR calibration star catalog specific to each sensor and filter combination is generated in units of watts/cm^2. By normalizing by the irradiance of Vega and converting to magnitude, the stellar catalog magnitude for each sensor filter is computed as well.

By measuring a series of IR calibration stars at different air masses, the extinction can be computed. However, dependent on the atmospheric absorption in the filter wavebands, this extinction curve may not be linear.

The IR stellar calibration procedure used is customized to the specific sensor and filter combination. Due to variations in atmospheric conditions, these calibrations are performed as close in time to the actual observations as possible. For practical considerations, most astronomers will measure responsivity, extinction, and other calibration parameters on a nightly basis.

Atmospheric Support

Atmospheric Instrumentation

The AMOS Atmospheric Instrumentation category of systems includes an array of sensors, signal processors, and data recording computers designed to characterize the atmosphere and monitor site weather conditions. This instrumentation is part of a continuing Atmospherics Characterization Program and can provide unique information for specific user requirements.

An array of meteorological sensors provides ground-level measurements of temperature, dew point, barometric pressure, wind speed, and wind direction (RMET data). Data is sampled continuously and recorded every three minutes. Meteorological history plots are available.

Communications

MSSS supports a variety of external communications including:

The Advanced Data Communications and Control Procedures (ADCCP) that carries classified imaging data.

The Space Command Digital Information Network (SDIN), a full-duplex dedicated communication line supplying classified connectivity to the world-wide Department of Defense (DOD) network. This circuit is used for classified mission data and administrative traffic.

Radar circuits that bring classified or sensitive but unclassified (SBU) radar data to MSSS through four dedicated lines. Radar data is used to provide hand off or direct slave target acquisition.

The Western Space and Missile Center (WSMC) Teletype circuit that supports test launches from Vandenberg AFB, CA.

A secure T1 Microwave Link between the observatory and the Kihei office facility that provides dedicated secure TCP/IP Ethernet connectivity between the MSSS and the Boeing-Maui offices. This connectivity can be used for off-site software development and remote operations.

A dedicated T3 fiber optic secure link that provides secure TCP/IP Ethernet to the MHPCC dedicated secure AMOS frame.

Internet access, available from SBU systems at the Kihei field office and the observatory.

Dial-up classified and SBU access, supported by a number of hosts at both the MSSS and the Kihei field office.

Special communication needs. Recent examples include aircraft communications by UHF radio. Classified special communications, both voice and data, can be made with the STU-III.

MSSS systems that play key roles in communications include the MIDAS and IDPS software projects. These are described below.

Communications Circuits

The Advanced Data Communications and Control Procedures (ADCCP), communications circuit was implemented in 1994 to provide direct secure data connectivity. It is a standardized protocol used by external sites to interface. The circuit operated initially at a rate of 9.6 KB per second. The capacity will increase to 56 KB and higher.

After data is collected at the MSSS and processed, image data is handed off directly from the Image Data Production System (IDPS) to the MOTIF Integrated Data Application System (MIDAS). MIDAS manages the external communications and segments the image data for transmission by the protocol converter, a Simpact(tm) communications device. The Simpact device handles low-level ADCCP protocol communications.

Aircraft Communications

Special experiments requiring prescribed flight paths of cooperative aircraft can be conducted. Control directly by AMOS personnel is by two installed (primary and backup) 20 watt AN/GRC-171 UHF radios out to a useful reception range of ~250 nautical miles.

Electronics Lab

The MSSS electronics lab is primarily used for corrective maintenance of computer and electronic site assets. Technicians are available during normal work hours to help diagnose and repair computer, video and electronic problems. Arrangements can be made for preparation and assembly of custom cabling, including fiber optic cables. The electronics technicians are also responsible for installation of power sources (up to 440 VAC @60 A)

The MSSS maintains a limited stock of parts for standard cables and simple electronic components, but no specialized electronic components are stocked.

Test equipment available for use includes:

- Logic Analyzers
- Oscilloscopes
- Multimeters
- ESD and Flat-Pack Soldering Stations
- Fiber Testing and Connector Kits
- Network Sniffer
- Spectrum Analyzer

Lasers

Strict rules are followed to maintain eye safety and avoid accidental damage of critical sensors on satellites. No laser can be allowed to radiate when there is any likelihood of illuminating a target for which the satellite owner has granted no permission. FAA agreements restrict normal laser operations to elevations greater than 25°.

Laser beams can be directed by the 3.6-meter telescope or either of the two beam expander afocal telescopes, the LBD and the BD/T. All are coudé systems, so the laser equipment can be rigidly mounted in the observatory building below the telescope floor level.

Site Laser Systems

Table 5-1. AMOS Active Lasers

Type	*Manufacturer*	*Wavelength (µm)*	*PRF / CW*	*Energy / Power*	*Pulsewidth*
CO_2	Textron	10.6 - 11.3	10 - 30 Hz	30 Joules	6 µs
CO_2	Laser Technics	10.6	10 Hz	5 Joules	100 ns
Nd:YAG (2)	Quantronix	1.064	CW	18 Watts	-
Nd:YAG	Holobeam	1.064	CW	500 Watts	-
Alexandrite	NASA-GSFC	Tunable: 0.720 - 0.790	10 Hz	0.35 Joules	50 ns
Argon	Coherent Model 70	0.514	CW	5 Watts	-
Argon	Spectra-Physics Model 171	Line-Tunable: 0.454 - 0.529	CW	6 Watts @ 0.514 µm	-
Krypton	Spectra-Physics Model 170	Line Tunable: 0.521 - .799	CW	4.7 Watts @ 0.647 µm	-

HI-CLASS

The High Performance CO2 LADAR for Space Surveillance (HI-CLASS) is a frequency agile, heterodyne transceiver consisting of a 30 J, 30 Hz, pulsed TEA CO2 laser and a quadrant detector receiver boresighted to the transmitter. The T/R switch is a polarizer. HI-CLASS has its own AIM driven track lag mirror and uses the VLT/LBD as its visible tracking system. The HI-CLASS TEA laser and receiver can switch between a pulse tone or pulse burst (mode locked) waveform and between short pulse (5 µsec) and long pulse (15 µsec) operation in 30 seconds. Transceiver line switching at 30 Hz is achieved by coordinated control of gratings in the TEA laser and the local oscillator cavities. Uses for HI-CLASS include measurement of range and Doppler shift with pulse tone, LADAR imaging with the 1.5 nanosec micropulses separated by 40 nanosec in the pulse burst mode, and DIAL technique LIDAR in the line agile mode of operation in either pulse tone or burst mode.

User Furnished Laser Systems

Potential laser users should be acquainted with several fundamental specifications necessary for operation of equipment on Haleakala:

- Regarding safety, electrical, optical, and environmental conditions, consult us early in your planning.
- Site conditions: The pressure altitude of over 3 km (10,000 ft) means:
    - Cooling fans adequate at sea level probably may not furnish enough airflow to cool chillers, etc.
    - The voltage breakdown strength of gaps and electrical leakage paths across insulators is lessened. A rough rule is that at 3-km altitude, the gap

breakdown voltage is only 2/3 as much as at sea level if both are at the same temperature.

- Corona is an electrical noise problem. No detectable corona at sea level does not guarantee corona free operation at the MSSS.

- Electro-Magnetic Interference: Remember that the MSSS has many very high-gain amplifiers following relatively unshielded detectors because of their optical access requirements. Therefore laser systems must be built with care to avoid emission of electrical radiation as well as noise on the power lines.
- Shielding is required: Military aircraft specifications offer guidelines to follow.
- TEA lasers and Eximer Lasers: These pulsed devices are particularly noisy when their electrodes are triggered, requiring special care with grounding. Consult us for further guidance.
- Acoustical noise is a potential health hazard in the relatively confined environment of the Observatory.

Typically, a VE's laser would be located in room 72, the coudé path room for the BD/T or in one of the six available AEOS coudé experiment rooms. They may be mounted on the existing optical benches in these rooms. For laser operations, one must have an ophthalmic examination including fundus photography, on record, and one is required to have the safety training specified in ANSI standard 136.1 and AFOSH 161-10 for the safe use of lasers. The SHEA department can supply this training.

If your experiment requires the use of special chemical agents, consult the MSSC Hazard Communication Program (HAZMAT). Be sure equipment is properly labeled and any Government Furnished Equipment (GFE) is so identified.

Mission Support Software (MSS)

Software developed for the control of the telescopes matches the Keplerian orbits of satellites to the pointing geometry of the telescopes on the rotating Earth. Measurable effects, including atmospheric refraction and the deviation of the Earth from a true sphere are considered. The mount control computers update calculations to inform the telescopes where to look. To acquire and track a selected object requires a state vector at a precise time. Using the laws of orbital motion, an ephemeris can be calculated. This is a table of angular (azimuth and elevation) position and slant range as a function of time. Coupled with sun position information the illumination of the object can be calculated. The fundamental equations for performing these calculations reside in the Mission Support System software. This software is contained in the MOTIF Integrated Data Application System (MIDAS).

The Mission Support System (MSS) consists of software that supports the requirements of mission allocated telescopes and sensors. The software is used for the following three major tasks:

- The Data Base Management Task (DBM)
- The Mission Preparation Task (MPT)
- The Data Reduction Task (DRT)

The DBM task consists of software that manages the I/O files that are used as databases by MSS software systems. Some DBM programs operate in real time while others are operator activated and controlled.

The MPT task consists of software that performs the mission planning and preparation functions for the MSSS operations. MPT software is run daily before operations for routinely tasked objects. The software may be run for specific user missions to determine feasibility of the proposed observations (AESOP program, see below).

The DRT task consists of software that performs the reduction of data collected on the History tapes by the MCS software.

The Mission Preparation Task

The software required to support the MSSS for operations and the Kihei Field Office for development and documentation, is executed daily to accomplish the Mission Preparation Task (MPT). The general function of the MPT software is to generate the information, data files and listings necessary to plan, schedule, and perform the operations of target acquisition, tracking and data collection and the software has useful simulation capability. Printouts of key interest to users are described below. In addition to printouts, electronic versions of each of the 3 MPT data products are available. These e-versions are available to users as Excel spread sheet files.

The universal date and time window for the evening's operations is the first input required by the MPT procedure, which executes a series of programs to produce the operational mission plan. The user may request entry of specific metric tasking for the object of his mission. In addition, if there are security considerations, an ATN (AMOS Test Number) will be used for tracking in lieu of the object number.

AMOS Ephemeris Satellite Orbit Predictor (AESOP) Program

A run of this program provides information about a known satellite concerning the availability of its being tracked in a given time window under specified illumination conditions. If the given window does not include a pass of the specified satellite, the window must be shifted or enlarged. The predictions are kept accurate by updates of their element sets. The program is particularly useful for visiting experimenters who wish to observe selected satellites during their stay on Maui.

The printout of program AESOP presents the following parameters for each day specified:

- Universal date (MM/DD/YY)
- Corresponding modified Julian day number
- Time of sunset at Observatory (UT HH:MM:SS)
- Time of end of evening twilight (UT)
- Time of sunrise (UT)
- Beginning and end of window 1 (HH:MM)
- Azimuth of sun at middle of window 1 (degrees)
- Elevation of sun at middle of window 1 (degrees)
- Azimuth of moon at middle of window 1 (degrees)
- Phase of moon at middle of window 1 (degrees)
- Beginning and end of window 2 (HH:MM)
- Azimuth of sun at middle of window 2 (degrees)
- Elevation of sun at middle of window 2 (degrees)
- Azimuth of moon at middle of window 2 (degrees)
- Phase of moon at middle of window 2 (degrees)

(All angles relative to the MSSS)

The AESOP program contains two sections. The first section lists each satellite in the order input, pass parameters, and a notation if the pass is scheduled or no pass was found. The following section, titled “accepted passes” lists each pass that meets the specified elevation and lighting constraints, in a time ordered sequence. The paper print out of AESOP contains both sections, useful to see what passes are accepted and rejected and for what reason a pass is rejected. The

Excel electronic version of AESOP uses only the accepted section. This is useful for sorting and statistical information on satellite passes, for example, the number of passes in a given period, the maximum and minimum culmination elevation, and the average length of a pass.

Satellite Ephemeris Preparation (SATPREP) Program

Specific passes or data collection missions may require an ephemeris, which is a table of pointing information tabulated as a function of time. The printout has range, azimuth, elevation, phase angle, and mount angle data points at specified time intervals that may be important in planning and scheduling considerations. The SATPREP program printout consists of 3 parts. The first part is a single title page listing program input parameters:

- Starting date
- Starting time in UT
- Rise elevation in degrees
- Ephemeris listing time step for each site
- Number of ephemeris listing for each site
- Constrained mount azimuth for each site
- Ephemeris listing page limit
- Pass search time limit

The second part is a single page listing the initial conditions of the pass. The data printed on this page includes:

- The ATN to be generated
- The UT date of the pass
- The modified Julian date of the pass
- The revolution number of the pass (if an SCC element set was specified for input)
- The age of the element set (if specified)
- The printout label for this case
- A column of the SCC element set data items (if specified)
- A column of the Earth Centered Inertial (ECI) state vector and time defined at mount motion
- A column of the Earth Centered Rotating (ECR) state vector and time defined at mount motion
- The orbit's apogee and perigee height

The final part consists of a sequence of ephemeris listings. Each page has a header with the following data items:

- The label
- The name of the site
- The sunset time (if the pass is closest to sunset), or morning twilight (if the pass is closest to sunrise)
- The ATN to be generated
- The UT date of the pass
- The mount azimuth in degrees, minutes, and seconds
- The shaft angle encoder (SAE) reading for the mount azimuth
- The evening twilight (if the pass is closest to sunset), or sunrise (if the pass is closest to sunrise)
- The revolution number of the pass (if an SCC element set was specified for input)

- The age of the element set (if specified)

A line of ephemeris data is printed for each time interval during the pass. The first block for each pass is printed out in 10-second intervals for finer resolution at the time of mount motion. Each line consists of 10 columns of data as follows:

- The universal time in HH: MM: SS format. An 'M' is appended to the time at mount motion and a 'C' is appended to the time of culmination.
- The slant range of the object from the site (in kilometers).
- The azimuth of the object as seen from the site (in degrees).
- The elevation of the object as seen from the site (in degrees).
- The polar axis angle of the telescopes, (1.2-meter and 1.6-meter), the gimbal azimuth axis (LBD), or the major axis angle (BD/T)(in degrees).
- The declination axis angle of the telescopes, (1.2-meter and 1.6-meter), the gimbal elevation axis (LBD), or the minor axis angle (BD/T) in (degrees).
- The polar axis velocity of the telescopes, (1.2-meter and 1.6-meter), the gimbal azimuth axis velocity (LBD), or the major axis velocity (BD/T) (in degrees/second).
- The declination axis velocity of the telescopes, (1.2-meter and 1.6-meter), the gimbal elevation axis velocity (LBD), or the minor axis velocity (BD/T) in (degrees/second).
- The satellite illumination ('LIT' or 'DARK').
- The sun-satellite-earth phase angle (in degrees).

This printout continues until the object descends below the specified rise elevation.

These lines of ephemeris data may be written to a file if specified. This would provide a file whose records consist of the ASCII text that is printed at each time step and is useful for creating tables or graphs.

The Excel electronic version of SATPREP contains the last section of the print out. This contains the entire sequence of ephemeris listings.

Mission Planning (MPLAN) Program

The MPLAN output is a multiple part listing to be used by operations personnel in performing the nightly metric operations of acquisition, tracking and data collecting. There are 9 parts to the listing:

- Part 1 is a title page.
- Part 2 input parameters: data, time window, and tasking parameters.
- Part 3 is a printout of the contents of the Daily Tasking File (DTF).
- Part 4 is a solar and lunar ephemeris page.
- Parts 5 and 6 are printed out as the program schedules tasked objects. The objects are scheduled from highest priority (lowest number) to lowest priority; parts 5 and 6 repeated for each priority level.
- Part 7 lists scheduled passes in time sequence. The format and data values are the same as in part 6.
- Part 8 is a set of work sheets to be used by the MCS console operators. The scheduled passes are listed in time sequence and data values listed include object number and tasking category, rise and set times, shadow transition times, culmination time and elevation, and mount azimuth. There are data boxes for element set number and age, polar and declination axis offsets at the time of acquisition, estimated visual magnitude, and the date and time of the acquisition.
- Part 9 is a set of extra blank work sheets.

VE’s will typically find the electronic version of AESOP most useful for planning purposes. AESOP can be used to generate opportunities on a large number of satellites for long periods of time. For example, a user may be interested in looking at all objects in a certain class of satellites over a 30-day period. The electronic version of AESOP will allow a user (or mission planner) to sort and filter passes and calculate the number of opportunities that meet mission constraints. SATPREP is most often used during the actual mission and is generated on only a single satellite at a time. The SATPREP program is generated for each mission a few hours prior to the pass over MSSS. The MPLAN program is most often used internally at MSSS to support Space Command metric operations. The electronic version of this program can be modified for user programs to provide information on multiple deep space satellite passes over MSSS.

Multimedia Support

In addition to the raw and processed data resulting from a mission, in many cases VE’s have found data reporting enhancement capabilities valuable aids to the presentation of their work. Visiting experimenters may elect to have carefully produced videotapes showing their apparatus being installed on the chosen telescope, combined with footage of the observatory scene. Coupled with captioned excerpts from the video data actually obtained during the mission, the video can be scripted and narrated to demonstrate to the world exactly what happened when the experiment was performed. Photographic documentation of details of the installation may be used in printed reports and journal articles resulting from the user's activities on Maui. The graphics facility can generate detailed quality overhead projection foils. Stock digitized images of our standard telescope and sensor packages may be included to furnish the background for depicting an installed experimental apparatus.

Video Production

Complete broadcast quality video production services, including full narration and music soundtrack library, are available for presentations of data, experiment and mission/task documentation, safety, and training. Program design, story boarding, on-location videotaping, incorporation of data imagery including split screen comparisons may be called upon for the enhancement of the user's message. The video production facility has access to years of past data tapes to compare with the most recent events. The video lab equipment includes an AVID 900 digital non-linear editing system, with titles and special effects capabilities. The AVID system allows for the integration of video, stills, and many types of computer graphics formats into the user’s final presentation. Video footage is shot on a Panasonic AG-EZI digital camera, with transfer to the AVID utilizing a Panasonic DVCPro AJ-D650 Digital Player Recorder. SVHS, VHS and _ “ SP Umatic formats are also available for videotaping and are digitized on the AVID for editing, with dubbing services provided to the user in these formats as well.

Photography Services

Skilled photographic services are available to the user. A large variety of still picture recording equipment including a large format copy camera, a 4 X 5, and a 2-1/4 square Hasselblad is available. Nikon quality lenses having fields of view ranging from 8.2° to 100° for the Nikon$_{TM}$ 35-mm single-lens reflex camera bodies provide suitable coverage under widely varying conditions.

Graphical Arts Services

Digital computerized presentation capabilities overlaid with hand drawn artistic renderings give the final touch to overhead projection foils and posters as well as line illustrations for technical papers. Stock line art of various views of the telescopes and their sensors is available. Alterations and additions may be visualized using digitized versions of the original art.

Optical Engineering Support

A dedicated Optics Group performs optical engineering and alignment activities at MSSS. The group is available to assess technical issues and evaluate beam trains using PC-based lens design programs. This allows experimenters and asset users to optimize optical performance as well as consider on-site modifications. The group also provides alignment support for all the major telescopes, performs systems integration activities, and maintains optics labs for instrument checkout and experimental work.

Optics Lab

The MSSS optics labs are located in the AEOS facility and are used for a wide variety of engineering and scientific purposes. These include functional checkout and calibration of sensors prior to telescope installation, equipment repair, experimental breadboarding, and evaluation of optical components. Optical benches ranging from 4' x 8' to 5' x 16' with vibration isolation are available. Standard optical bench components (e.g. mirror mounts, translation stages, posts and platforms) are stored in the labs. In addition, a large selection of optical components including mirrors, splitters, ND filters, notch filters, polarizers, and beam expanders are available.

Test equipment available for use include:

- Zygo 4" Fizeau interferometer
- Itek laser unequal path interferometer
- WaveFront Sciences CLAS-2D Shack Hartmann wavefront sensor
- K & E alignment scopes
- Wild T3000 autocollimating theodolites
- Astronomical telescopes (8" to 14")

MSSS Coating Facility

The Optics Group also maintains the MSSS Coating Facility within the AEOS facility. The facility contains a 20" Veeco vacuum chamber, a 96" Stokes chamber, monitoring equipment, flow benches, cleaning areas, and storage cabinets. The systems provide an on-site capability for recoating virtually all the telescope mirrors, transfer optics, and auxiliary components.

The 20 inch 7760 Series Veeco vacuum chamber system is designed to deposit high quality coatings and dielectric overcoats. The unit consists of a four-stage oil diffusion pump, a mechanical pump, a chamber consisting of a bell jar and hoist, and a controls system. Base metal coatings include aluminum, gold, and silver. Protective overcoat materials include magnesium fluoride and silicon monoxide. Current capability is limited to single layer overcoats.

The Stokes 96-inch vacuum chamber is a horizontally oriented unit designed for depositing metal coatings on large circular mirrors. The unit has a split tank with each section independently mounted on a rail system. The main section contains the filament assembly, which is powered by a mobile 40 KVA power panel. The frame supporting the removable head also supports the diffusion pump, baffle and vacuum control panel. The system is equipped with a Stokes #412-10 Microvac pump that initially rough pumps the system and backs a CVC 20" diffusion pump during high vacuum operation. Mounted to the diffusion pump is a multi-coolant baffle, which is used to condense and trap vapors and prevent back-streaming of pump vapors. The chamber has been used to successfully re-coat the 1.2-m primaries and the 1.6-m primary.

Safety, Health, and Environmental Affairs

The primary mission of the Safety, Health, and Environmental Affairs Department (SHEA) is to promote a safety awareness culture and to preserve the environment while maintaining safe and compliant operations. As an Air Force Installation, the MSSS is required to comply with all applicable Federal, State, Local and Air Force laws and regulations.

The site is unique in that it poses challenges to a SHEA program. O&M and R&D operations:

- are conducted at a 10,000 ft elevation;
- occupy space on state owned land that is federally leased;
- are home to endangered and threatened species;
- are adjacent to Haleakala National Park; and
- border areas of native Hawaiian cultural resources.

In parallel with these challenges, the main goals of AMOS are to conduct safe workplace operations and to be recognized stewards of the environment. The SHEA department recognizes that the regulations appear to be restrictive at times however, preplanning and working with MSSS POCs can minimize program impacts.

Health and Safety Program

Anticipating, recognizing, and reporting potential hazards are the keys to preventing accidents. In order to resolve any issues that may arise as a result of your activities on site, some basic questions (not all-inclusive) should be asked:

- Will chemicals be used in the operations?
- What type of training do I need to perform my tasks? Have I received this training?
- Do I have the appropriate safety equipment?

The list below includes but is not limited to elements of a health and safety program however, it provides a sample of areas visiting experimenters must comply with:

- Noise, lasers, HAZCOM, fall protection, emergency preparedness, electrical safety
- Applicable Regulations: OSHA, AFOSH, NFPA, NEC
- Lead Agencies: HIOSH, Maui County Fire Department, AFRL, FAA

Environmental Compliance Program

With the broad band of environmental protocols applicable to the site, susceptibility to non-compliance situations may occur. In order to resolve any issues that may arise as a result of your activities on site, some basic questions (not all-inclusive) should be asked:

- Do I need permits for my equipment or processes? (long lead times)
- Is there a potential for generating hazardous waste? Solid waste? Wastewater?
- Is my work going to impact the historic/cultural sites near the site?

The list below includes but is not limited to elements of the environmental compliance program; however, it provides a sample of areas visiting experimenters must comply with.

- Air emissions, hazardous waste, lead and lead compounds, wastewater, Hawaiian artifacts
- Applicable Regulations: RCRA, NEPA, CAA, CWA, TSCA, DOT
- Lead Agencies: EPA, Hawaii State Department of Health, DLNR

Towards achieving the goals stated above, visiting experimenters are asked to work with the POC who is coordinating your arrival on site. It is important to AMOS that the transition into the facilities and the ongoing operations is seamless. Once on site, the SHEA department will support your stay to ensure that work is performed in a safe manner and protection of the environment is maintained.

Visiting R&D Experiments Guidelines

With the multitude of resources available at AMOS, visiting experimenters have successfully performed many complex experiments over the last 30 years. Although the location of the site is thousands of miles from the mainland, the common air shippers perform well; shipping times for most items is seldom more than a few days. Nevertheless, contingency planning is very important and frequent contact with your AMOS sponsor is urged as your experiment time approaches. Machine shop facilities and electronics parts are limited at the observatory. Visiting experimenters are advised to bring their own hand tools, suitably identified, for use during their stay at AMOS. Section 7 of this manual describes the process for soliciting use of the AMOS facilities and instrumentation by users requiring measurement or visiting experiment programs.

Frequent visitors and those working at the observatory for more than two consecutive days are required to attend safety briefings on

- Driving;
- Mechanical, Chemical and Electrical Procedures and;
- Laser Radiation Safety (if appropriate)

in accordance with site safety policy.

Chemical Use

If the experiment requires the use of special chemical agents, consult the *Boeing HAZMAT Guide*, part of the Hazard Communication Program. Equipment must be properly labeled and any Government Furnished Equipment (GFE) items so identified.

Laser Equipment

Visitors planning laser-based experiments are urged to observe the cautions and recommendations to be found in this section for the design and preparation of their laser equipment prior to shipment to Maui. For laser operations, visitors must have an ophthalmic examination including fundus photography on record, and are required to have the safety training specified in ANSI standard 136.1 and AFOSH 161-10 for the safe use of lasers. The SHEA department can supply this training.

HAZMAT

If one is handling potentially hazardous material, all actions are required to follow HAZMAT procedures.

Security

The Boeing Company is responsible for visitor control at the MSSC. All visits shall be coordinated well in advance of the proposed visit to allow ample time to process and obtain appropriate approvals. A point-of-contact will be established for all visits and experiments conducted at the MSSC. The point-of-contact shall be a Maui resident point-of-contact. The point-of-contact is responsible for coordinating, obtaining approval, and hosting the visit, experiment, and/or project.

Visit Requests - Access to Classified Information and Material

All visits and/or experiments where access to classified information or material is anticipated will require a Visit Authorization Request (VAR) from the Security Office of the proposed visitor’s company/organization. The VAR shall be prepared in accordance with the National Industrial Security Program Operating Manual (NISPOM) Chapter 6.

The clearance certification for all facilities shall be addressed and forwarded via mail or fax as follows:

The Boeing Company/OMAN2
Attention: Visitor Desk
535 Lipoa Parkway Suite 200 FAX 808-874-1600
Kihei, Maui HI 96753 Voice 808-875-4500

Visit Authorization Requests

The Visit Authorization Request shall be in accordance with the NISPOM, Chapter 6, and at a minimum, contain the following information:

- Visitor's organization name, address and telephone number, assigned CAGE Code if applicable and certification of the level if the facility security clearance.
- Name, date and place of birth, and citizenship of the employee intending to visit
- Certification of the proposed visitor's personnel clearance and any special access authorization required for the visit;
- Name of person(s) to be visit
- Purpose and sufficient justification for the visit to allow for determination of the necessity of the visit, and
- Date or period during which the visit is to be valid.

Visitor and Point of Contact Responsibilities

All visitors shall have a Maui resident point-of-contact (POC). POCs will be from Det 15, AFRL; Det 3, 18 SPSS; Boeing; Litton PRC; Textron Systems; Thermotrex, or Oceanit.

It is the responsibility of the POC and visitor to ensure:

- A *Visitor Notification/Coordination Form* is processed through the Visitor Desk a minimum of three days prior to visit. See Appendix F.
- visitor(s) bring proper identification
- visitor(s) sign the visitor register upon arrival each day at each facility for the duration of the visit
- visitor(s) wear visitor badges in a visible location at all times
- ensure visitor(s) photographic, programmable and recording equipment has approval for use
- visitor(s) are escorted where required
- visitor(s) are not left in the facility after hours without approval to lock and alarm the facility
- visitor(s) are not granted access to computers without approval and briefings
- visitor(s) badges and keys are returned to the Security Office or Visitor Control Desk at the end of the visit

Access to Classified Material

All visits and/or experiments where access to classified data or material is anticipated will require a Visit Authorization Request from the Security Office of the proposed visitor's company/organization.

Request for Use of Equipment

No software, photographic, programmable or recording equipment is permitted at the MSSC without prior approval. This includes, but is not limited to, personal film cameras, camcorders, and audio tape recorders. Visitors desiring to bring equipment for use at the MSSC should notify the point-of-contact well in advance to coordinate and process approvals. Approvals will be obtained by processing a *Request for Use of Equipment,* through the point-of-contact, to the Security Office. Please refer to Section 7 for information concerning shipping and receiving of equipment.

Request for Area Access

The POC will process all requests for access to Dairy Road, MSSC, Premier Place, and RME through the Security Office. Area access will be based on the visitor(s) clearance and need-to-know. Approvals will be obtained by processing the *Request for Access* through the Security Office. See Appendix F.

Request for AIS Access

The POC will process all requests for access to the unclassified, sensitive but unclassified (SBU) and classified computers. Access to computers will be based on the visitor(s) clearance and need-to-know. Approvals will be obtained by processing the *AIS Access Authorization and Briefing Form* through the Security Office. See Appendix F.

Special Data Handling

All data processing equipment that will be used by a visiting experiment program must be itemized and described prior to shipment to MSSC. An authorization to use user-provided ADP equipment will be required prior to the transport of the equipment to the site.

If the data to be processed, generated or stored is CLASSIFIED, a security guide is required, and the data handling equipment (now considered "RED") must meet the MSSC TEMPEST Officer's approval. Stored CLASSIFIED data must be handled in accordance with the instructions of the Facility Security Officer (FSO). Upon completion of the visitor's experiment, the CLASSIFIED data, whether on diskette, video tape, digital tape, exposed photographic material, or other media must be brought to the Kihei Security Office by Boeing’s official secure courier. The data will then be prepared for transport to the visitor’s designated Security Officer, with proper documentation, wrapping and mailing instructions. CLASSIFIED data must not be allowed to remain in integral data storage devices, such as PC hard disks, for unsecured shipment back to the visitor's facility.

Timing System

The AMOS Timing System maintains synchronized time to within 5 microseconds of the UTC (Coordinated Universal Time) at the U.S. Naval Observatory (USNO). GMT or Greenwich Mean Time, UT or Universal time, and Z or Zulu time are the same. They refer to the time on the Greenwich meridian. UTC or Coordinated Universal Time is essentially the same, but determined by the USNO and broadcast by WWV and WWVH and used by the Global Positioning Satellits (GPS).

The Timing System may be logically separated into three subsystems; Generation, Synchronization, and Distribution. The purpose of the generation subsystem is to produce an extremely accurate reference frequency from which other needed frequencies and time codes can be generated for distribution to the mounts and instruments needing them. Synchronization matches the generated frequency to the USNO standard clock. GPS and WWVH are used for synchronization sources.

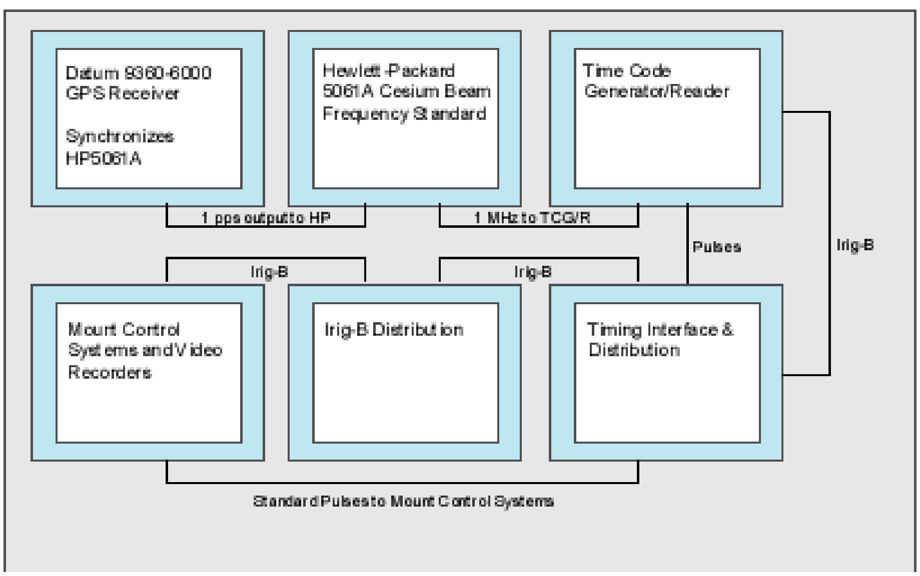


Figure 5-1. AMOS Timing System Schematic

The principal source of USNO time is the constellation of GPS. When the satellites are available, the AMOS master clock function is a Datum, Inc. model 9390-6000 GPS Receiver. The GPS reference is within 100 nanosec of the UTC time at the USNO when it is time locked on GPS satellites.

The Hewlett-Packard Model 5061A Cesium Beam Frequency Standard maintains the time reference, which is synchronized to the GPS receiver. The time reference frequency is passed to a Systron Donner 8150 Time Code Generator/Reader (TCG/R), the main element of the Distribution System. The TCG/R supplies a coded pulse to the Mount Control Systems for time-tagging data and provides a variety of time codes including IRIG-B and standard pulse rates to instrumentation, camera systems, and recorders.

Figure 5-1 is a block diagram of the AMOS Timing System that also provides timing pulses for user applications. To find the Maui time of an event to occur at a given GMT, subtract ten hours from the UTC, GMT or Z time. The local time for Maui, and the entire State of Hawaii, is Hawaiian Standard Time (HST). Hawaii does not observe Daylight Savings Time.

Video Systems

Table 5-2. AMOS TV Cameras and Recorders

VIDEO CAMERAS					
MFGR.	MODEL	TUBE	CONFIG	CATH DIA.	USING SYSTEM
Scanco	SC-401	Vidicon	ISIT	40 mm	MATS
Scanco	SC-401	Vidicon	ISIT	40 mm	AATS
Scanco	SC-25	Vidicon	ISIT	25 mm	LLLTV
Cohu	2856	Vidicon	ISIT	16 mm	AMTA boresight
RCA	TC1040/H	Vidicon	ISIT	16 mm	LBD
RCA	TC2500	Silicon Matrix	Vidicon Ultricon	16 mm	(spare)
RCA	TC1040/H	Vidicon	ISIT	16 mm	1.6 boresight
RCA	TC1040/H	Vidicon	ISIT	16 mm	BDT
Photometrics		[CCD-Kodak KAF-1400]	[special masks]		PHIAT
Pulnix	TM 745	[CCD]	[not a tube]	16 mm diagonal	MAIS
MITLL	[special]	[CCD]	TE cooled	3 mm sq	ADONIS

VIDEO RECORDERS AND REPRODUCERS		
MFGR	MODEL	TAPE SIZE
Sony	VO-9600	All use NTSC [color] _-inch tape
Sony	VO-5850	
Sony	VO-2611	
Panasonic	NV-9240XD	
Panasonic	AJ640 [digital]	
Panasonic	AJ450 [digital]	

The AMOS facility makes extensive use of standard NTSC video for acquisition, fine tracking, and imagery of visible targets. This has resulted in a video system consisting of an assortment of cameras, monitors, and solid state detectors (CCDs), digital processing equipment, automatic TV trackers, and broadcast studio quality video tape recorders. The video system operates within the US NTSC television standards. This system is compatible with standard U.S. video equipment operating at 525 lines/frame and 60 frames/second.

Table 5-2 lists the present inventory of video cameras at MSSS as well as the available video processing equipment which can be used for special applications. Most of these TV cameras are dedicated to particular sensor system applications.

Video Tape Recording

Recorders used include Sony and Panasonic Umatic and Panasonic AJ640 and AJ450 digital video cassette recorders which are used for a range of dedicated applications. These are used for routine mission support and in applications where supplemental recorded data is required. The recorders are mounted in consoles in both the SOC and AEOS control rooms. Before any mission, one person can make sure every sensor using videotape has a fresh cassette in place in its recorder. For viewing with standard high quality television monitors, 3/4-inch tape permits several generations of video processing and editing before significant image degradation occurs.

Video Annotation

The purpose of video annotation is to automatically record operator selected settings (which filter is in place, what field-of-view has been selected are examples of settings) as a function of time on the videotapes produced by sensors that make television-like images. The "housekeeping" information is recorded permanently between frames thus becoming part of the data. The IRIG-B time is recorded on the audio channel. In playback, the data is presented alpha-numerically superimposed on the frame if desired. Comparing video-taped events with the mount-history data is simplified and unambiguous.

Figure 5-2 is a block diagram of the method of recovering the annotated information. Note that all or portions of the information can be re-recorded to appear in the picture area permanently if desired.

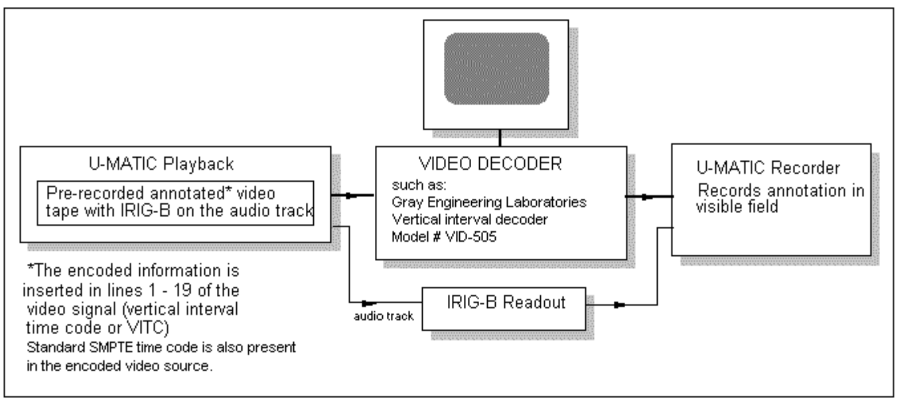


Figure 5-2. Video Annotation Recovery

OCS Upgrade

The OCS video system provides for the distribution, annotation and recording of video signals, all under software control. The distribution of video signals is by a set of video switch matrices. One switch matrix is provided for each operator station. A central switch matrix, which is used for routing between telescopes, is installed at the MTO console. Each STO has an associated set of video tape recorders (VTRs) which can be controlled via the video management (VMGT) software. Each telescope video subsystem has software controllable annotation hardware that permits annotation of information onto video signals.

Data Analysis

Section 6 - DATA ANALYSIS and DISTRIBUTION

It is of paramount importance that the customer/user receive the data needed in the correct form specified and in a timely manner. Data sources may include mount operator logs, environmental measurements, mission predictions, astrometric measurements, time-tagged raw and calibrated digital and video data from MSSS and user-supplied sensors, and laser transmitter parameters when appropriate. Depending on the user's needs, this collected data may be prepared for delivery in several different package formats. Three tasks are usually involved in the preparation of data for a specified or requested data package: assembly of the components of data, data archiving, and special processing of the data.

Data Treatment

In post mission, all photometric, radiometric, and video (image) data components and supporting information is collected and archived. The first step in data analysis is generation of a mission profile. This may include reviewing video tapes of AATS, MATS, or other imagery, to locate data segments (matching IRIG time codes to events imaged), ensuring that the data and supporting calibrations are properly annotated (filter in use, which FOV, etc.), surveying GEMINI imagery (keyed to the events of interest by time), and compiling accompanying computer-generated reports and other mission operations reports.

The process of archiving consists of identifying storage areas and maintaining logs for accumulated data. Appropriate data receives special treatment. The data is logged and controlled, utilizing document control procedures as outlined in the Industrial Security Manual (ISM); data is classified as required.

Further processing, performed at the Kihei offices, consists of data fusion, data interpretation, and other special functions to provide the data user with his requirements. For example, to obtain a data package that includes AMTA signature data, in addition to the data, Jones (black body) calibrations are processed for detector responsivity. Stellar calibrations may be referenced to estimate the sky conditions. Infrared mission data is then processed for radiant intensity, and photometric signatures are processed to obtain normalized visual magnitude (MV). Finally, a report is produced that includes the following:

- element sets and state vector data
- pass geometry
- calibration data and results
- visible and IR photometric plots
- visible and IR imagery
- environmental data (wind speed and direction, temperature, pressure, dewpoint)

In addition to data packages, the capability for extensive fusion of data of various kinds and interpretation for Space Object Identification (SOI) and Mission Payload Assessment (MPA) may be required. Specialized data reports using advanced data analysis may be produced upon request.

Calibration and Validation

Table 6-1 and Table 6-2 outline the available AMOS sensors, the calibration techniques used in pre- or post-mission data collection and the recording formats used in data collection for each sensor. The evaluation and validation criteria used in analysis of raw data is listed. The data is processed or edited prior to dissemination to MSSS Users.

Table 6-1. Sensor Validation Criteria

Sensor	Validation Criteria
GEMINI	Nominal sky background measurements, valid Point Spread Function (PSF) star radii, track stability, how well object is resolved, and appropriate computed Freid coherence parameter (R_0)values
GEMINI IR	Intensity of the recorded image of the object, brightness, how well object is resolved, track stability
LLLTV	Intensity of image of object, track stability
MAIS	Intensity of image of object, how well object is resolved, glints, track stability
AMTA/CMP	Valid instrument calibration-detector responsivity, valid stellar calibration with respect to the atmosphere, SNR, track stability
ARS	Valid stellar calibration and atmospheric extinction values, SNR, track stability
AO/VIS	
AATS, MATS, BATS, LATS, LFAT, LATT	Relative brightness of images, stability of track

Required data packages and reports are prepared and prompt delivery to the user is ensured.

Table 6-2. Sensor Calibration and Data Format

Sensor	*Calibration*	*Raw Data Format*
GEMINI	Photometric and double stars	Digital data in Gemini format
GEMINI IR	IR stars, black body	Digital data in Gemini format
MAIS	Photometric and double stars	U-matic and DVCPro video tape
LLLTV	Photometric and double stars	U-matic and DVCPro video tape
AMTA	IR stars, black body	Strip chart, Digital data
CMP	Photometric stars	Digital data
ARS	Photometric, IR, and double stars	Digital data

Table 6-3. Processed Data Formats

Sensor	*Processed Data Format*
GEMINI	Digital imagery data in GEMINI and TIFF-PL format
GEMINI IR	Digital imagery data in GEMINI and TIFF-PL format
MAIS	U-matic, VHS and DVCPro video tape optical disk, TIFF-PL
LLLTV	U-matic, VHS and DVCPro video tape
AMTA	Strip chart, Calibrated digital data
CMP	Normalized digital data
AATS, MATS, BATS, LATS, LFAT, LAAT	U-matic, VHS and DVCPro video tape
RMET	MSExcel tables and plots on floppy disk
LWIR	
ARS	Digital data
AO/VIS	

Data Distribution

The MOTIF Integrated Application System (MIDAS), provides capability for collecting, recording, displaying, editing and processing photometric, radiometric, positional and range data, from the 1.2, 1.6 and BDT systems, and dispatching data to be transmitted by SDIN.

The system is capable of simultaneous, real-time acquisition and storage of metric, CMP, and AMTA data. Concurrent with its data acquisition function, data from a completed track may be called up for processing. The data is displayed graphically in high-resolution (4096 X 4096) in both its raw and processed form.

The system provides the operator with:

- manual editing
- smoothing and integration
- processing of both stellar and black body data for determination of responsivity and extinction parameters
- database management functions to maintain current, mean, and nominal values of calibration parameters
- background subtraction
- reduction of data to desired physical parameters
- generation of hard copy reports and plots
- formatting and transmission over SDIN to HQ AFSPC or other specified user.

MOTIF Integrated Data Application System (MIDAS) Software

The MIDAS software runs on a Silicon Graphics SGI 4D210GTX and encompasses:

- external communications
- reception of Space Command mean element sets
- reception of Space Command tasking messages
- transmission of AMOS/MOTIF metric data in accordance with the Space Command B-3 format
- transmission of AMOS/MOTIF CMP and AMTA signature data in accordance with the Space Command SIGTRANS format
- mission planning (see paragraphs on mission planning software for details)
- data collection and processing of photometric, radiometric, and positional (metric)
- recording
- displaying
- editing
- applications library for
- inter-computer communication
- algorithms
- conversions

Image Data Production System (IDPS) Software

IDPS software is an end-to-end data product system driven by both site and customer requirements. IDPS runs in two modes: production or analysis. The production mode requires a video frame grabber and is currently supported at MSSS on the following Silicon Graphics workstations: Power Series, Personal Iris (4D/310 VGX or 4D/440 VGX) (1280 X 1024 resolution) or Indigo (1024 X 768 resolution) and IRIX 4.0.1+ Operating System. The analysis mode does not require any frame grabbing hardware, and therefore can run on a wider group of Silicon Graphics platforms. Currently IDPS supports any Silicon Graphic Workstation that will support GL and is running IRIX 5.3 or 6.2.

The IDPS at MSSS:

- digitizes image data from video-based sensors
- reads in digital GEMINI TIFF image files
- accesses MIDAS for state vector information
- overlays information on the image
- orientation vectors
- metrics
- satellite models
- packages images in standard TIFF format

Section 7 - VISITING EXPERIMENT GUIDELINES

The capabilities described in the previous sections may be used in experiments designed for specific Visiting Experimenter (VE) requirements. VE process must be followed, regardless of whether plans are to become a user of the features described or simply by requesting the observatory functions to collect measurement data. The VE process is the subject of this section. Please note that the terms *Visiting Experiment* and *VE Program* may be used interchangeably in this manual.

Authorization

Any United States Government agency or contractor representative can be authorized to use AMOS facilities. Non-government organizations can also be granted access. Criteria for access are:

- Suitability of the VE's research or measurement objectives in light of the AMOS and Air Force Research Laboratory mission;
- Priority of the requested support in view of other tasking and scheduled activities; and
- Scientific or technical merit of the proposed research.

Special Requirements

Coordination at least one year prior to anticipated operations is necessary if program support requires modification of the facility or revisions to the lease between the U.S. Air Force and the landholder, the University of Hawaii, or both. Similar prior coordination is required for experiments that may involve significant environmental impacts or health considerations. In these cases, AMOS will coordinate and prepare Conservation District Usage Application (CDUA), Environmental Assessment (EA), or other required National Environmental Protection Agency (NEPA) compliance documentation. AMOS will also obtain appropriate Occupational Safety and Health Agency (OSHA), Hawaii State Department of Land and Natural Resources (DLNR), and Department of Health (DoH) clearances and permits.

Intended introduction and use of Government Furnished Equipment (GFE) must be declared early in the planning process to provide the Air Force Research Laboratory adequate time to ensure contractual compliance. All VE equipment to be brought to the site should be properly identified and tagged and inventoried. Submission with sufficient lead-time of program requirements documentation containing special security or environmental requirements will ensure proper adherence to security procedures and compliance with all applicable environmental standards and procedures.

VE's should consult "The Maui Hazard Communication Program" if their experiment requires chemical agents. For laser operations, VE personnel are required to have an ophthalmic examination including fundus photography, on record, and are required to have the safety training specified in ANSI (American National Standards Institute) Standard 136.1 and AFOSH (Air Force Occupational Safety and Health) 161-10 pertaining to the safe use of lasers. The MSSS Safety Officer can supply further guidance on laser-specific requirements and arrange for required examinations and training.

VE's may consult the end of this section for guidance on shipping their equipment to and from Maui. Security matters concerning magnetic storage media are also addressed in this appendix. If it is for use on the summit, VE’s are advised to make sure their equipment operates properly at the 10,000 ft. altitude.

Initial Contact

A prospective VE should contact the AMOS VE Programs Coordinator, or alternately, the AMOS Chief Scientist, by telephone at (808) 874-1541, facsimile at (808) 874-1640, or by mail at: the Air Force Research Laboratory (AFRL/DEBI); 535 Lipoa Parkway; Kihei, Maui, HI 96753.

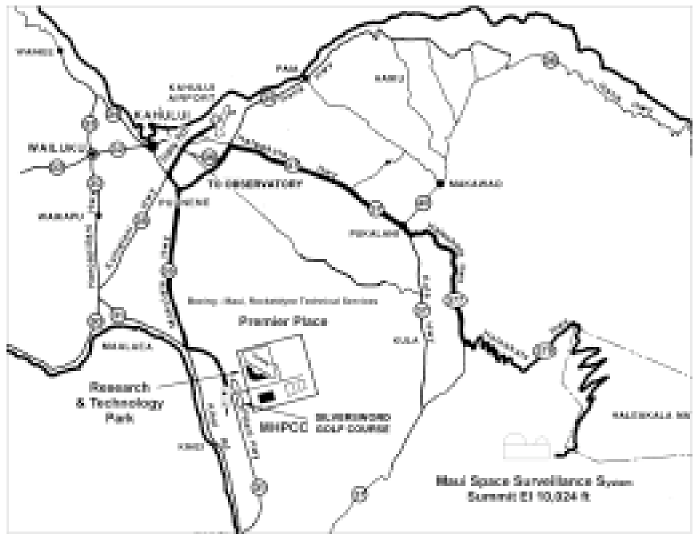


Figure 7-1. AMOS Site Map

Information sought in initial VE contacts includes:

- Outline of program objectives
- Details of required measurements
- Approximate time frame of desired support
- Points of contact (address, telephone, etc.) for programmatic and technical coordination.

Information developed during this initial exchange will provide the basis for the assignment of a Responsible Engineer (RE) who will accomplish implementation of the program.

The AMOS *Pre-Experiment Survey* can serve as a useful outline of general requirements to guide these preliminary discussions, and should be completed and forwarded as soon as practicable to support AMOS planning and preparations for a follow-on site meeting, if indicated.

Interface Meeting/Site Visit

A meeting between VE representatives and AFRL/DEBI and the support contractor's scientific, operational, engineering, and safety personnel may be conducted. Although a face-to-face meeting is desirable, especially because it affords the opportunity to visit the observatory and inspect the facilities and instrumentation selected for experiment support, meeting objectives can be satisfied by telephone, particularly if the VE is already familiar with the site.

Although timing of this meeting hinges on the technical complexity of preparations for the desired support, it may be governed by fixed launch schedules. No less than three months lead time prior to the commencement of operations is sought, with six months preparation time being the desired minimum. The VE presents a description of his technical requirements and measurement objectives at this meeting in sufficient detail to support preliminary planning and scheduling estimates.

Interface Information

There is a wide variation in the level of facility and personnel support required for VE programs. Since one experiment may require only a platform or site for the emplacement of instrumentation, while another may require engineering design, complex fixtures, new instrumentation, facility modifications, detailed test planning, special software development, and operations support, AMOS personnel will seek the following information:

- What site facilities and instrumentation will be used?

- What accommodations/alterations must be made to the facility, mounts, or instrumentation to incorporate VE's equipment?
- What are the integration points between the Visiting Experiment's instrumentation and the site instrumentation?
- What special software interfacing might be needed?
- What level of operations support is needed to perform the experiment(s)?
- What is the visitor's schedule requirement?
- What is the level of security required?

Visitor Safety

There are three phases to safe accomplishment of a visit to the observatory. The first is the drive ascending nearly 10,000 ft. to the observatory. Take some warm clothing. The second phase concerns the time you are at the site and the third is the return to near sea level. The third phase often starts from a considerably colder environment than the start of the first phase.

Driving

Choose an automobile that has been properly maintained and that is not restricted (by the automobile rental agency) from ascending the volcano road. Ensure that the headlights on your rental vehicle can be turned off. Headlights must be turned off prior to approaching the observatory. Reputable rental car facilities on Maui can supply good automobiles for the drive to the summit. There is no food available at the summit.

Before starting, make sure the tires and brakes are in good condition and the windows are clean. Wear sunglasses when the time for ascending the mountain requires driving into the sun. Be on the lookout for cattle and downhill bicyclists on the road. Night driving requires special diligence and patience because the road is narrow and unlit. For most cars, a half tank of gasoline will be more than adequate to go from Kihei to the observatory and return. Since fuel is not available on the highway to the observatory above the junction of Highways 377 and 40, about 28 miles from the summit, fuel the vehicle accordingly.

Above the 3,000-foot elevation, much of the road to the observatory is steeply graded, with many hairpin turns and long sections of road with narrow or no shoulders. During the drive, you may encounter weather that varies from warm and clear at sea level to fog and ice at the summit. If you need the heater in the automobile, do not turn off the air conditioner; it acts as a dehumidifier, to prevent condensation on the windows. You must use lower gears to aid braking during descent.

At The Observatory

Enter the observatory parking area at a speed of 5 mph or less. At night, switch to parking lights at the advisory sign at the head of the driveway into the parking area. Park in a marked stall, and lock your vehicle. Note the automobile's location, it may be very dark when you leave. You may appreciate wearing a sweater or jacket. The telescope domes are kept at the outside ambient air temperature.

All visitors must sign the visitor control log located in the observatory entrance reception area. An on-site Security Representative will issue a visitor's badge. Visitors must have prior written approval from Det 15 AFRL to visit the site. If a security clearance is necessary for your visit, a certified visit request must be on file at the Boeing - Maui Security Office. Once inside the facility, obey all posted safety information, and do not handle or operate equipment unless authorized to do so. Visitors must sign out and return their badge when leaving.

The Altitude

You may notice physical effects at the summit, as your body compensates for the diminished oxygen content of the air. Your respiration rate may automatically increase, so it is advisable to slow down a bit to prevent shortness of breath. If you do get lightheaded or short of breath, compressed breathing oxygen is readily available. Do not hesitate to ask anyone on site to assist you in locating and using one of the tank and mask units.

Be aware that it can be both very cold and very dry at the observatory. Bring a sweater or windbreaker, and if you plan to be on site for more than a couple of hours, drink extra fluids during your stay to prevent dehydration. Fatigue and lessening of thinking skills occur more quickly at higher elevations, and you should plan your workday to compensate. Allow more time for sleep and avoid the intense sun to prevent severe sunburn.

Mission Preparation

Effective mission planning is a central feature of an active and professionally operated field site. This is particularly important when several VE Programs require concurrent support that must also be coordinated with other observatory research and development activities. This is accomplished through anticipating, planning, and scheduling of potentially competing test requirements in a manner that satisfies all VE requirements while assuring efficient utilization of all observatory resources.

Elements of mission planning at AMOS include:

- Analysis of mission-specific experiment, test, or measurement objectives for compatibility with site capabilities
- Development of tailored calibration and collimation procedures for various mount/sensor combinations
- Coordination and scheduling of site activities to minimize facility down time, including unnecessary instrument changes,
- Coordination of multiple mounts/telescopes/sensors at one or more observational sites for single or multiple simultaneous activities
- Pre- and post- visit coordination with each VE, furnishing the investigator with appropriate manuals, interface and configuration documents, operational procedures, and post-experiment evaluations to assess results and guide future planning
- Special considerations (active vs. passive, etc.)
- Setting of program scope and objectives to maximize value to the AFRL/DEBI mission and cognizant scientific communities
- Creation of a document detailing the mission scenario. This document is called the Mission Instruction and Operations Plan.

Software Aids to Mission Planning

The software required to support the MSSS for operations and the Kihei Field Office for development and documentation, consists of a number of programs, that are executed daily to accomplish the Mission Preparation Task (MPT). The general function of the MPT software is to generate the information, data files and listings necessary to plan, schedule, and perform the operations of target acquisition, tracking and data collection. The section on the Mission Preparation Task provides additional information.

Special Considerations

An example of a special consideration in planning for field experiments at AMOS is the active experiment. While those that receive data only are considered passive, those that use lasers to illuminate or stimulate a target in space are termed "active". The passive experiments typically use one or more of the receiver telescopes on site. The Active experiments usually use one or more of the beam directors, sometimes use self-contained optics provided by the Visiting Experimenter, and may use the other telescopes as receivers as well. Active experiments are generally more support intensive because there is usually more instrumentation and integration required, and there is typically more testing done prior to active operations.

Whenever an active test is performed, laser beam radiation safety must be considered. Predictive Avoidance (PA) procedures must be followed to protect other satellites. FAA air traffic control procedures and radar support must be brought on line via established Controlled Firing Area (CFA) protocols to prevent the accidental illumination of aircraft. Enhanced on-site safety supervision is also necessary to positively prevent laser radiation exposure incidents with site personnel, and through established AMOS Plane Watch procedures, to visually detect low flying aircraft that might not be observed on radar.

Mission Instruction and Operations Plan (MIOP)

A document describing in detail the steps to be performed for the experiment is prepared. It is called the Mission Instruction and Operations Plan (MIOP) and contains:

- Final, approved, program objectives
- Primary and Secondary sensor assignments
- Required calibrations/accuracy standards
- Detailed description of operations scenario:
- Schedule/Event Time Sequence
- Lighting Conditions
- Trajectory(ies) and Impact(s)
- Radar Support
- Deployment/Ejection Phenomena
- Communications/Coordination
- Test/Measurement procedures
- Data requirements:
- Recorder Assignments
- Data record Media/Format Specifications Classification and Distribution of Data
- Reports Required
- Safety Procedures and Constraints.
- Special Security Requirements
- Hardware design, procurement, fabrication
- Software development
- Installation and testing of hardware and software
- Preliminary measurements

Operations

Following the planning stages of a VE's Measurement or Visiting Experiment Program, AMOS personnel will support the integration, performance verification, test and evaluation, and operations stages. This is discussed in the following subsections.

Integration

The integration stage of an experiment is divided into several discrete steps. The first step is the preparation of a proper environment for the experiment. It includes such tasks as preparing a sensor platform on a receiver telescope, installing an optical bench in a designated laboratory space, or modifying structure by incorporating a screen room or increasing the electrical power capacity to a sensor location.

Before an experiment environment is prepared, careful consideration is given to the VE's instrumentation dimensions, power and cooling requirements, optical requirements, installation of additional cable or fiber optic lines, and special requirements, such as EMI screening, laminar flow clean benches, or supplies of special gasses. Laser operations are especially sensitive to the observatory environment; e.g.: whether the laser wavelength and power density is compatible with the optical elements on available beam directors.

The next step is the determination of equipment design and alterations required to support the experiment. The best method for integrating the equipment into the site's systems is determined. This may require electrical, mechanical, or software modifications. An optimum approach is selected based on a joint review of cost and time impacts by both VE and support personnel.

Unless other arrangements are made, assigned logistic support personnel handle the receiving and off-loading of VE equipment shipped to the Shipping and Receiving Office (in Kahului), and then by truck to the site. Do not ship directly to the observatory. Details of this process are furnished in Appendix E. Crates and containers are counted, inspected for damage, verified with the VE, and unpacked if requested. Site personnel then assist in equipment installation, which may involve mechanical mounting, electrical wiring, coolant hookup, and optics installation. Although the expertise is available to provide complete set up support for Visiting Experiments, the level of support actually provided is based on the VE's needs and other priorities of the planned test operations.

Once the visitor's equipment has been set up, it is integrated into the site facilities at the appropriate integration points. Typical examples include:

- incorporating a VE's laser safety shutter circuit in a laboratory door interlock system, or
- the linking of a closed loop tracking device to the AMOS tracking mount control system.

Performance Verification

Although the proposed test design is thoroughly evaluated during preparations for experiment integration, a final performance verification occurs after the instrumentation is in place to identify any problems that may have been overlooked.

The defining event of this stage is a final end-to-end review of the Experimenter's design for instrumentation and set up. Any remaining mechanical, optical, electronic, or software design problems are identified, and corrective action implemented. Necessary changes can usually be made at this time in a cost effective and timely manner.

Test/Evaluation

This stage occurs after the basic set up is complete. Site support personnel will assist the Visiting Experimenter in verifying proper operation and integration of VE-supplied test equipment with observatory equipment and facilities. They will work closely with the Visiting Experimenters to quickly resolve any emergent problems. Examples of this support would be shielding of an electronic component or rerouting an electric cable to reduce EMI, or modification of control software to accommodate an unanticipated requirement.

After the VE's equipment set up is fully checked out and integrated with site instrumentation and facilities, the operations and technical support crews become an integral part of the experiment. A test schedule is determined, and the operations crew is assigned to appropriate duty stations such as mount control, camera control, laser operation, sensor control, recording, and any other duties necessary to attain experiment objectives.

The Experiment

Most experiments, even those intending to use active devices (lasers), begin with passive tests. A typical initial test is to observe stars and sun-illuminated satellites with the Visiting Experimenter's instrumentation. Data are collected and recorded, the integrity of the data path is evaluated, and calibration data are obtained. If the experiment setup is complex, testing might begin on only basic performance parameters, with full system check out performed by the Visiting Experimenters.

The next step is to perform one or more dry runs, as necessary to ensure that all operations and technical support personnel are thoroughly familiar with their assigned duties prior to, during, and following the test. Dry runs are tailored to realistically simulate test pointing vectors, dynamics, and time lines, to ensure that test equipment performance is properly validated in actual test scenarios. Please refer to Appendix E regarding calibration requirements for VE test equipment.

When all the preliminary activities are successfully completed, the actual experiment is conducted. Careful attention to rehearsals pays dividends in successful missions. The experienced operations crews perform support actions to assure the success of the mission.

Support Actions

AMOS support for program execution is provided via a number of specific support actions during active measurements or test operations. The assigned Responsible Engineer (RE) will provide site interface and engineering/scientific support throughout this phase.

Preparations for tests of experiments:

- Prepare Primary & Backup Key Person & Crew Assignment Lists:
    - Test Director & Test Conductor
    - Telescope, Dome, & Sensor Operators
    - Technicians-- Mechanical, Electronic, Video, Electrical Atmospheric Technician & Engineer
    - Computer Operator & Technician
    - Photographer & Video Operator
    - Communications Operator
    - Safety/Environmental Technician & Engineer
- Conduct Detailed Overview Briefings for Crew
- Conduct Rehearsals
- Nominal Scenario;
    - Standard Recovery Procedures (Computer Dropout, etc.)
    - Simulate Non-nominal Performance (i.e., Deployments)
- Coordinate/Schedule External Support:
    - Radar
    - Aircraft
    - Ground Sites
    - Surface Craft

        - FAA (re: CFA activation for laser operations)
- Active support of tests/experiments:
    - Schedule Crew/Support Personnel
    - Conduct Event Briefings/Debriefings
    - Plan/conduct Dry Runs of Test Event
    - Perform Pre- and Post-Test Event Calibrations
    - Coordinate and Direct Test Support Activity
    - Assemble and Dispatch Data Packages

Reporting

The assigned Responsible Engineer (RE) will provide report generation and engineering/scientific support throughout this phase. Reports will be generated as required, including Flash Reports, Quick-look, 36-Hour, 30-Day and Final Reports.

Following Measurements

The assigned Responsible Engineer (RE) will provide site interface and engineering/scientific support throughout this phase, including:

- Site Deactivation,
- Disposition (i.e., pack, ship, store, etc.) of Visiting Experimenter's Equipment,
- Data Reduction and Analysis, and
- Prepare Technical/Program Completion Reports.

Visiting Experimenters and Equipment on Maui

Government Owned Equipment

A broad range of government owned equipment is available to support visiting experimenters. To best serve the visitor's needs, a list of requirements should be presented at least two weeks prior to the anticipated arrival at Maui Space Surveillance System (MSSS). If the visiting experimenter is a contractor, the contract should indicate approval to use government owned equipment. Since danger to personnel and/or the environment could result from improper usage of machine shop equipment or a forklift truck, proof of competency may be established beforehand by a letter to the visitor's sponsor on Maui describing relevant experience.

Initial Inventory

All equipment, government owned or otherwise, designated for introduction into MSSS for experiment support must first be inventoried and tagged. A copy of the inventory list will be provided to the User's host or sponsor for verification prior to the commencement of set-up preparations. Another inventory will be performed jointly by the sponsor and the User prior to departure.

Calibration of Test Equipment

All User's test, measurement, and diagnostic equipment (TMDE) brought to the site must have appropriate property identification tags and a current calibration sticker indicating traceability to the National Bureau of Standards (NBS) such as, a sticker from any Air Force

Precision Measurement Equipment Laboratory (PMEL). With prior coordination, calibrated TMDE for visiting experiment support may be available.

Moving MSSS Equipment

All MSSS property and equipment that is to be moved from one location to another (from room to room, as well as from building to building) for more than one day, requires a "Move Ticket" for documenting the move. Hand tools, multi-meters, and similar equipment do not require move tickets. Visiting experimenters are advised to bring their own suitably identified hand tools for use during their stay on Maui.

User's Electronic Equipment

User's electronic data handling equipment, computers and peripherals, must be listed by name and function along with the approximate dates of arrival and departure. All equipment must be approved prior to installation. This list is to inform, (a) the resident TEMPEST officer, (b) the resident Computer Systems Security Officer (CSSO), (c) the Facility Security Officer (FSO), and (d) the Site Commander (refer to Appendix F for suggested format). If the data to be processed, generated or stored is CLASSIFIED, the data handling equipment must meet the resident TEMPEST officer and Site Commander approval. If systems are intended to be interfaced to existing MSSS computers additional approval may be required. CLASSIFIED data will be handled in accordance with the instructions of the CSSO and coordinated through the FSO.

Upon completion of the visitor's experiment, all CLASSIFIED data/material will be processed through the Document Control Center/Communications Center at the MSSS to the Kihei Security Office for return mailing as authorized.

Laser Equipment

Visitors planning laser-based experiments are urged to observe the cautions and recommendations to be found in Section 5 for the design and preparation of their laser equipment prior to shipment to Maui. If laser operation by visiting experimenter personnel is contemplated, an ophthalmic examination with documented fundus photography is required.

Shipping and Receiving

Refer to Section 8 for shipping addresses. Containers should be marked to the attention of the project name (or sponsor). The equipment will be held at the Shipping and Receiving Office for the User. Unless precluded by schedule constraints, the User is expected to unpack and check his shipment against the inventory list. The packing material may be stored at this location. There is no test equipment for checking performance at the Shipping and Receiving Office.

Transportation to the MSSS

The User may then arrange for transportation, when available, to deliver his equipment to the Observatory and/or Kihei. TEMPEST approval, when required, will be accomplished at the site. When the experiment is completed, the User's equipment will be inventoried by the User and his sponsor, and transported back to the Shipping and Receiving Office for repackaging and shipment back to the User's own facility. Please do not attempt to ship items directly to the observatory.

Preparation for Shipment

It is very important to Hawaii's fragile environment that you personally ensure that your equipment is clean and free of seeds, insects, insect eggs and other larvae. The State of Hawaii and the National Park Service have urged extraordinary safeguards to prevent the introduction of new species of any kind. The summit of Haleakala is home to a number of rare and endangered species that are under continuous threat from the introduction of exotic flora and fauna.

If special chemicals are required, please review the safety section in Section 5 concerning hazardous chemical policy. Provide a list of chemicals to be introduced to the site prior to arrival. Liquid nitrogen and other cryogens are available with sufficient prior arrangement.

Section 8 - Summary

While the AMOS will continue to support the needs, requirements and tasking of the United States Space Command and Air Force Materiel Command, it is becoming increasingly open to Research and Development of all kinds, including projects with NSF, educational and astronomical institutions. Proposed R&D at the MSSC will be evaluated as to its consistency with the AMOS mission. Please refer to Section 7, “Visiting Experiment Guidelines”, for procedures.

Initial contact is encouraged either by mail at:

Det 15, AFRL
535 Lipoa Parkway, Suite 200
Kihei, HI 96753

by phone at: (808) 874-1541

or on the Web at: http://www.maui.afmc.af.mil

Addresses

AMOS Program Office
Det 15, AFRL
535 Lipoa Parkway, Suite 200
Kihei Maui, HI 96753
Telephone: (808) 874-1541
Fax: (808) 874-1640

The Boeing Company
535 Lipoa Parkway, Suite 200
Kihei Maui, HI 96753
Telephone: (808) 875-4500
Fax: (808) 874-1600

Visit Requests

All classified visits to the Maui Space Surveillance Complex (MSSC) require a visit request prepared in accordance with the Industrial Security Manual, Section 6. Clearances and visit requests are sent to the site contractor, The Boeing Company, at the address above.

Shipping and Receiving

Many experimenters require equipment to be shipped to and from Maui. Containers should be marked to the attention of the project name (or sponsor). Some detailed discussion of this need is discussed in Section 7. The Shipping and Receiving Office address is:

The Boeing Company
360 Ho'ohana Street #B110
Kahului, Maui, HI 96732
Telephone: (808) 877-1514 or (808) 877-0931

Section 9 - Appendices

Acronym List and Glossary

AATS	AMOS Acquisition Telescope System (finder on the 1.6-meter)
ACO	Administrative Contracting Officer
ACONS	AMOS Control Software
ADA	Advanced Data Analysis
ADAP	Advanced Data Analysis Program
ADAPS	Atmospheric Data Acquisition and Processing System
ADATS	AMOS Data Transmission System
ADCCP	Advanced Data Communication Control Procedure
ADI	Air Defense Initiative
AEOS	Advanced Electro-Optical System (the new telescope facility, first light in 1997)
AESOP	AMOS Ephemeris Satellite Orbit Predictor (AMOS Software)
AFOSH	Air Force Occupational Safety and Health
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AFSPC	Air Force Space Command
AIAA	American Institute of Aeronautics and Astronautics
AMOS	Air Force Maui Optical Station, an acronym of historical importance
AMTA	Advanced Multicolor Tracker for AMOS (infrared radiometric array on the 1.2-meter)
ANSI	American National Standards Institute
AOA	(Army) Airborne Optical Adjunct
AOS	Acquisition Of Signal
ARPA	Advanced Research Projects Agency (now DARPA)
ASAT	Anti Satellite
ASCII	American Standard Code for Information Interchange
ASN	AMOS Star Number
ASP	Atmospheric Sensor Package (Seeing Monitor) or
	Analog Signal Processor

ASR	AMOS Spectral Radiometer (Infrared sensor on 1.6-meter side Blanchard, removed 1994)
ATM	Asynchronous Transfer Mode
ATN	AMOS Test Number
ATP	Acquisition, Tracking, and Pointing
AZ	Azimuth
BATS	BDT Acquisition Telescope System (finder on the BDT)
Baud	number of digital units transmitted per second
Baudot	five unit digital code for transmission of teletype data
BDT	Beam Director Tracker (also termed BD/T)
BET	Best Estimate of Trajectory
BIB	Blocked Impurity Band (Type of detector)
Blanchard	Precision-ground instrument mounting surfaces.
BLIP	Background limited infrared photoconductor
BMD	Ballistic Missile Defense
BMO	Ballistic Missile Office
BPI	Bits Per Inch
BPS	Bits Per Second
BRDF	Bi-directional Reflectance Distribution Function
Bus	Upper stage of ICBM from which RVs are deployed.
Bus	Communications path that handles multiple signals.
byte	A group of 8 bits
CCD	Charge Coupled Device
CCIR	Consultative Committee International Radio
CCRB	Configuration Control Review Board
CDRL	Contract Data Requirements List
CDUA	Conservation District Usage Application
CFA	Controlled Firing Area
CIC	Combined Intelligence Center
CID	Charge Injection Device
CIK	Crypto Ignition Key (enabling device for use with STU III)
CLIP	Cirrus Lidar Probe (ruby laser and receiver to detect cirrus clouds-removed 1994)

CMP	Contrast Mode Photometer (wide dynamic range visible glint photometer mounted on the 1.2-meter)
C_n2	Atmospheric Turbulence Structure Parameter
COMSEC	Communications Security
CONUS	Continental United States
CPU	Central Processing Unit
CRT	Cathode Ray Tube
CSSO	Computer System Security Officer
CVF	Circular Variable Filter (changes spectral characteristics smoothly with rotation)
CW	Continuous Wave (characteristically unmodulated)
DARPA	Defense Advanced Research Projects Agency
DBMS	Data Base Management System
DCAC	Defense Communication Agency Circular
DCP	DTS Calibration Parameters file
DCS	Defense Communications System
Dec	Declination (one axis of an equatorial telescope mount, see Pol).
DIAL	Differential Absorption LIDAR
DIS	Defense Investigative Service
DoD	Department of Defense
DoE	Department of Energy
DPS	Data Processing System
DRAM	Dynamic Random Access Memory
DSP	Digital Signal Processor
DTS	Data Transmission System
EA	Environmental Assessment
ECI	Earth Centered Inertial (coordinate system)
ECM	Electronic CounterMeasures
ECR	Earth Centered Rotating (coordinate system)
ELSI	Enhanced Long Wave Spectrometer/Imager (Infrared imaging array sensor having both medium and longwave 128 X 128 arrays)
EMI	Electro-Magnetic Interference
E-O	Electro-Optical

ERTS	Earth Resources Technology Satellite
ETR	Eastern Test Range
EVA	Extra-Vehicular Activity
FACSFAC	U. S. Navy Fleet Area Control and Surveillance Facility, located on Ford Island, Pearl Harbor, Oahu HI.
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FCL	F-Center Laser
FFT	Fast Fourier Transform
FLIR	Forward-Looking Infrared (an infrared night vision device)
f/	"f" number, the ratio of the focal length to the aperture in optics
FOV	Field of View (typically in degrees, arc minutes, or arc seconds)
FPA	Focal Plane Array (examples are the ELSI arrays)
FSO	Facility Security Officer
FWHM	Full width at Half Maximum (refers to laser beam diameter, typically)
GBL	Ground-Based Laser system
GEMINI	
GFE	Government-Furnished Equipment
GEODSS	Ground based Electro-Optical Deep Space Surveillance
GFP	Government-Furnished Property
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
HIANG	Hawaii Air National Guard
HBF	Horizon Break File
HEL	High Energy Laser
HOE	Homing Overlay Experiment
hoku	Hawaiian word for star.
HST	Hawaiian Standard Time (Hawaii does not use Daylight time) also
HST	Hubble Space Telescope
IAU	International Astronomical Union
IBC	Impurity Band Conduction, a class of detectors.

ICI	Imagery/Communication Interface
IDPS	Image Data Production System (Software for assisting analysis of image data)
IMSAT	Imaging Satellite
IRAPS	Image Recording and Processing System
IRCCD	Infrared Charge Coupled Device
IRIG	Inter-Range Instrumentation Group (sets range instrumentation standards)
IRIG-B	A timing standard format based on 100 pps.
IRIS	3-dimensional graphics workstation by Silicon Graphics, Inc. also
IRIS	InfraRed Information Symposium
IRV	Inter-Range Vector
ISIT	Intensified Silicon Intensifier Target
ISM	Industrial Security Manual
ISO	International Standards Organization
ITV	Instrumented Test Vehicle
IUS	Inertial Upper Stage
JANAP	Joint Air Force, Navy, Army Publication
JDN	Julian Day Number
JEDEC	Joint Electronic Devices Engineering Committee
JSC	Johnson Spaceflight Center
kona	Hawaiian word for leeward side or leeward coast.
LBD	Laser Beam Director
LCEF	Launch Centered, Earth-Fixed (coordinate system)
LLLTV	Low Light Level Television (sensitive camera on the B37 telescope)
LN_2	Liquid Nitrogen
LOS	Line-of-Sight
LPM	Lines Per Minute
LWIR	Long Wave Infrared
mag-tape	magnetic tape data storage medium
MAIS	MOTIF Advanced Imaging System (Fast-aperture visible imaging system on the B37 telescope)
makai	Hawaiian for the sea, toward the sea, seaward.

MATS	MOTIF Acquisition Telescope System (finder on the 1.2-meter telescopes)
mauka	Hawaiian word for inland, toward the mountain.
mauna	Hawaiian word for mountain, Mauna Kea is "White Mountain".
Mb	megabyte
MCS	Mount Control System
MIDAS	MOTIF Integrated Data Applications System (software-running on Silicon Graphics SGI 4D/210 GTX))
MIOP	Mission Instruction and Operation Plan (scenario document governing execution of a mission)
MISPREP	Missile Preparation (software for preparing for observation of missile launches).
MM	Mount Model (part of Mount Control software that accounts for individual mount/sensor peculiarities)
MMP	Monthly Maintenance Plan
MOA	Memorandum of Agreement
moana	Hawaiian word for ocean.
MOTIF	Maui Optical Tracking and Identification Facility
MOU	Memorandum of Understanding
MPA	Mission/Payload Assessment (a mission of the MSSS)
MPLAN	Mission Planning Program
MR	Maintenance Report (document used to report a deficiency and to record the repair effort)
MSDS	Material Safety Data Sheet (applies mainly to chemical agents)
MSSC	Maui Space Surveillance Complex (includes MSSS and GEODSS)
MSSS	Maui Space Surveillance System
MSS	Mission Support Software
MTF	Modulation Transfer Function (a measure of fidelity of an imaging system)
M_V	Apparent Visual Magnitude
MWIR	Medium Wavelength Infrared
NASA	National Aeronautic and Space Administration
NAVAID	Navigational Aid
NBS	National Bureau of Standards

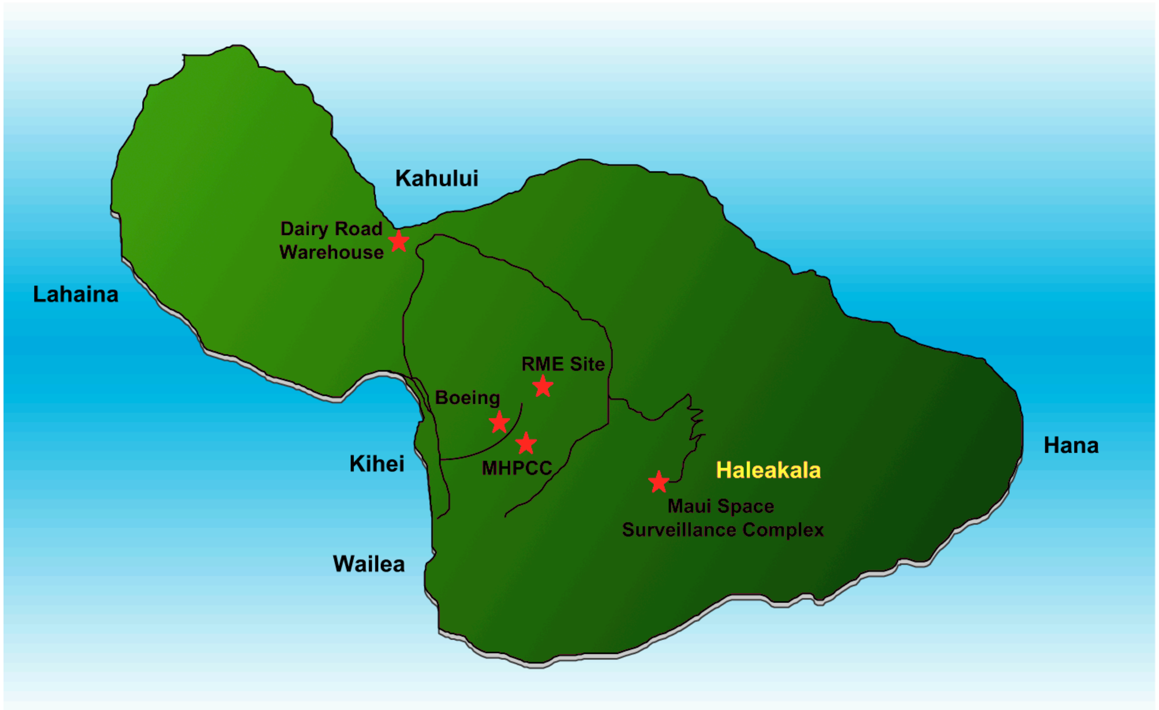
ND	Neutral Density (optical filters to change intensity without altering the spectral characteristics)
NEFD	Noise Equivalent Flux Density
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Air Defense Command
NTSC	National Television Standards Committee
OCF	Object Correlation File
OCPREP	Object Correlation Preparation
OCR	Optical Character Reader
OCS	Observatory Control System
PA	Predictive Avoidance
PIPE	Parallel Image Processing Engine.
PM	Preventive Maintenance (scheduled maintenance performed periodically to maintain operational status)
PMEL	Precision Measurement Equipment Laboratory (an Air Force calibration laboratory with Bureau of Standards traceability. One is located at Hickam AFB, Oahu)
PMR	Pacific Missile Range-Pt Mugu CA
PMRF	Pacific Missile Range Facility-Barking Sands, Kauai HI
PMT	PhotoMultiplier Tube (vacuum tube device capable of extremely high gain, can count photons).
POC	Point of Contact
Pol	Polar (one axis of an equatorial telescope mount, points to the celestial pole, see Dec).
POL	Polar, geometric coordinates (pointing location) of an object
PPE	Personal Protective Equipment (gloves, goggles, ear plugs, etc.)
PtSi	Platinum silicide infrared CCD (removed 1994)
puka	Hawaiian for hole that goes all the way through, aperture, or gateway
QA	Quality Assurance
QDP	Qualified Data Package

RA	Right Ascension (an astronomical measure of location in sidereal time).
RAID	Redundant Array of Inexpensive Disks, A method of recording data at very high rates.
RMET	Routine Meteorological data (temperature, wind speed and direction, etc., also rmet)
rms	Root Mean Square
r_o	Atmospheric Correlation Scale Length (a measure of "seeing" ability). Fried's coherence diameter.
ROM	Rough Order of Magnitude, applied typically to cost estimates
ROM	Read Only Memory, computer memory that is permanent, non-volatile.
RS-232	Industry standard computer connection
SAC	Strategic Air Command, now part of USAFAWC
SAO	Smithsonian Astrophysical Observatory
SAR	Special Analysis Report
SAR	Synthetic Aperture Radar
SATPREP	Satellite Ephemeris Preparation (software)
SBU	Sensitive But Unclassified
SC	Strategic Command
SCC	Space Control Center
SDIN	Space Command Digital Information Network
SDP4	NORAD Perturbation Model for propagation of Deep space satellite elements
SGP4	NORAD Perturbation Model for propagation of Near Earth satellite elements
SIGTRANS	Signal Transmissions
SIMAN	System for Interactive Multispectral ANalysis
SIT	Silicon Intensifier Target
SMC	Space and Missile Center
SMPTE	Society of Motion Picture & Television Engineers (sets TV Standards)
SNR	Signal-to-Noise Ratio
SOA	Special Operating Area (refers to airspace under DoD control)

SOC	Surveillance Operations Center (main control room at the MSSS)
SOI	Space Object Identification (a mission of the MSSS)
SOR	Starfire Optical Range (optical facility at Air Force Research Laboratory in New Mexico)
SPADOC	Space Defense Operations Center (System in Cheyenne Mt. CO)
SPIE	The International Society for Optical Engineering
SSN	Space Surveillance Network
STS-#	Space Transportation System-number (refers to the shuttle of a particular mission number)
TEA	Transverse Electric field excitation Atmospheric pressure (a kind of laser, typically producing gain-switched pulses)
TEMPEST	Security standard for computers and data handling electronic hardware, to prevent compromising of the data being processed.
TCG/R	Time Code Generator/Reader
TFR	Tightly Folded Resonator (A kind of diode pumped neodymium laser)
TGS	Transportable Ground Station
TMDE	Test, Measurement, and Diagnostic Equipment (this equipment should have calibrations traceable to the National Bureau of Standards)
TOO	Target Of Opportunity
U-Matic	3/4 inch industrial video tape cassette format
UCT	Uncorrelated Target
UNIX	Computer operating system/trademark of Bell Laboratories
USNO	U.S. Naval Observatory
UTC	Coordinated Universal Time, (GMT) or (Z) as defined by the USNO.
VAFB	Vandenberg Air Force Base (California launch site for Western Test Range)

VCR	Video Cassette Recorder (U-Matic, Hi-8, and VHS are used at MSSS)
VGH	velocity, ground range, and height
VHS	Video Home recording System (1/2-inch video tape cassette)
VIS	visible wavelength data
VPR	Video Production Recorder
VSP	Visible Sensor Package
VTR	Video Tape Recorder
WSMC	Western Space and Missile Center
WTR	Western Test Range
Zulu	Greenwich Mean Time (GMT), also (Z)

Maui Information



Useful Information

Table of Metric Equivalents:

1 (statute) mile = 1609.344 meters

1 (statute) mile = 0.86898 nautical miles

1 nautical mile = 1852-meters exactly, by definition.

1 micrometer (same as micron) = 0.000001 meters = 0.001 millimeters

1 radian = 57.2958^{o} of arc

1 milliradian = 0.0572958 degrees = 3.43775 arc minutes = 206.265 arc seconds

1 arc second = 0.004848 milliradians = 4.848 microradians or roughly 5 microradians

Local Maui Time:

MSSS time is based on a standard time clock system to synchronize telescope motions with the given orbital parameters. MSSS uses UTC (Coordinated Universal Time), which is the time at the zero meridian (Greenwich UK), but as determined by the U. S. Naval Observatory. The state of Hawaii does not use Daylight time, therefore the conversion is the same the year-round. The timing equipment used to regulate and synchronize operations is described in Section 5 on support systems.

Subtract 10 hours from the "hours" part of the UTC, GMT, or Zulu time to find the local time which is HST or Hawaiian Standard Time and the time zone is (W) or "whiskey."

Facts about the Observatory:

The floor areas, electric power availability, and air conditioning capability an the location of the site are listed below:

Square footage:

45,000	AEOS Facility
15,500	AMOS Main building
7,100	AMOS Domes, upper and lower floors
10,700	GEODSS Total, including domes
5,100	Technical Support Building

Power Availability:

60 HZ Electrical Power:

1,000 KVA
- 440 VAC, 3-phase
- 208 VAC, 3-phase
- 120 VAC, 1-phase

75 KVA U. P. S.
- 208/120 VAC, 1-phase

Two 750 KVA Emergency Generators (full site capability)
- 440 VAC, 3-phase (line-frequency dependent timing devices may drift due to small errors in frequency control).

400 HZ Electrical Power:

Dedicated Motor Generator, 115 VAC, 1-phase, 8.7 A

Cooling Systems:

Air Conditioning:
127 Tons (approx. 80% Utilized)
160 Tons Air-cooled Condensing Capacity.

Two Major Separate Glycol Cooling Circuits are also available

Location Coordinates:

The observatory (referenced to the point on the azimuth axis at the height of the intersection of the polar and declination axes of the 1.2-meter telescope mount) is located at a geodetic altitude of 3058.2-meters (10,024 feet) close to the crest of the dormant volcano Haleakala at:

Latitude	20:42:30.5 (20.7084)° N
Longitude	156:15:28.7□(156.2578)°

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